THE UNIVERSITY OF ALBERTA

EVAPOTRANSPIRATION AND WATER BALANCE IN THE STURGEON RIVER BASIN, CENTRAL ALBERTA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "EVAPOTRANSPIRATION AND WATER BALANCE IN THE STURGEON RIVER BASIN, CENTRAL ALBERTA," submitted by VIJAY KUMAR SHARMA in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The research was undertaken to estimate evapotranspiration and water balance patterns in the Sturgeon watershed north of Edmonton. For this purpose the empirical techniques developed by Thornthwaite, Holdridge and Turc were applied to the temperature and precipitation data of ten years from 1960-1969 for six stations close to the watershed boundary.

Thornthwaite's potential evapotranspiration for the drainage basin varied from 19.5 to 21.0 inches as against 13.5 to 14.5 inches computed by the Holdridge method. The values in both cases increased eastward.

The average actual evapotranspiration for the study area estimated by the Thornthwaite method (at 4 inch soil moisture) and Turc's technique varied from about 14.5 to 16.5 inches and 10.5 to 11.5 inches respectively. The values in both cases increase westward.

Further investigation has shown that Thornthwaite's method, though not entirely satisfactory, is superior to Holdridge or Turc techniques.

A difference of over 50 per cent was noted between the water surplus computed by the Thornthwaite method at 4 inch soil moisture and observed runoff from the Sturgeon watershed. The Thornthwaite method, if applied to the study area without any allowance for differing moisture storage patterns would result in erroneous values of moisture surpluses and deficits.

ACKNOWLEDGEMENTS

I am greatly indebted to my supervisor, Dr. Ian MacIver, for guiding my first steps in the field of water resources and for his constructive criticism of the thesis at all stages. Special thanks are due to Dr. A.H. Laycock for stimulating discussions during the course of the research and suggesting improvements in the manuscripts. My appreciation is expressed to M/S Carl Primus, Paul Sindhu and Dick Heywood of the Department of Water Resources, Government of Alberta, Edmonton for the information and data they supplied and to Prof. R.W. Longley, Geography Department, who kindly allowed free access to his library. Finally, I wish to thank Miss Irene Lyszczyk for typing the thesis, and Mr. Jack Chesterman for reproducing the diagrams.

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CHAPTER I

INTRODUCTION

The research was undertaken to evaluate empirical and semi-empirical techniques of computing potential and actual evapotranspiration from the climatic data, and to compare surpluses computed by these techniques with the measured surpluses in the streams. Only those techniques which employ easily measurable temperature and precipitation data, reported by almost every meteorological station, were considered. The techniques considered in this thesis are those developed by Thornthwaite (1948), Turc (1953) and Holdridge (1959). Holdridge determines potential evapotranspiration on an annual basis whereas monthly potential evapotranspiration values obtained by the Thornthwaite technique may be aggregated to obtain annual potential evapotranspiration. Turc's technique computes annual actual evapotranspiration.

There are two possible ways in which the methods of determining potential evapotranspiration may be discussed. The more detailed way would lie in the realm of physical hydrology involving complicated mechanism of energy transfer between the earth-atmosphere interface. "Despite the fact that an evapotranspiration formula on a physical basis is nowadays available, no one has yet succeeded in drawing up a formula wholly derived from theoretical considerations" (Mohrmann and Kessler, 1959, p.17). Evapotranspiration is a complex process affected by numerous factors which taken together would complicate a theoretically derived formula to the extent that it would be virtually impracticable.

A second and more general approach followed in this research is through the application of existing formulae to a prairie environment.

Thornthwaite, Turc, Holdridge and many other methods have a pronounced empirical background, supported by a number of experimental investigations in particular climatic environment. However, their suitability to any other environment can be a matter of controversy and subject to investigation. Since the study area is an experimental watershed, data collected in the field under different vegetation, crop and soil conditions may be compared to the results obtained by this research. This type of approach is essential in establishing the strength of these techniques. The degree to which these methods apply to a given environment will be determined by the extent to which the most important meteorological factors affecting the process of evapotranspiration were considered. A detailed discussion of these processes appears in Chapter II.

A direct outcome of the Thornthwaite technique is its application to climatic water balance, a detailed account of which follows in Chapter IV of the thesis.

THE STUDY AREA

The Sturgeon watershed, a little north of Edmonton (Figure 1), extends approximately between latitudes 53° 24' 45" and 53° 58' N, and longitudes 113° 10' 2" and 114° 59' 55" W. It has a maximum length and breadth respectively of about 67 miles in east-west direction and 33 miles in north-south direction. The drainage area of the basin at the mouth of Sturgeon River near Fort Saskatchewan is about 1,310 square miles.

Access to different parts of the drainage basin from Edmonton is easy. For example, the eastern parts of the drainage basin can be reached by highway 37, the mid-eastern by highway 2, the middle portions

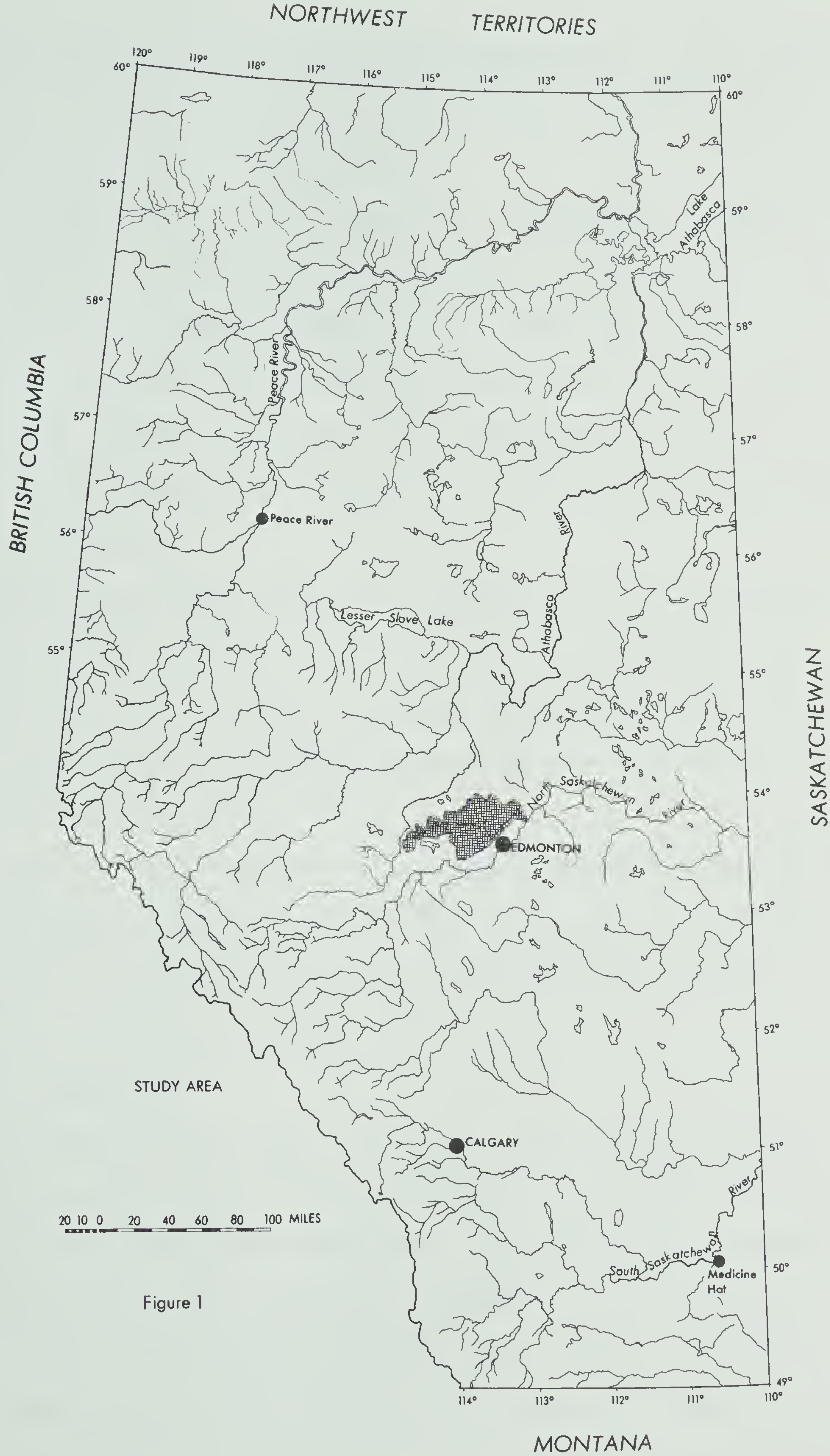

NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
Lake Athabasca
Peace River
Peace River
Athabasca River
Lesser Slave Lake
North Saskatchewan River
EDMONTON
CALGARY
South Saskatchewan River
Medicine Hat
STUDY AREA
20 10 0 20 40 60 80 100 MILES

Figure 1

by highway 43 and the extreme western limits by highway 16. The interior of the drainage basin can be approached by section roads which are all connected to the highways mentioned above.

The watershed is of a size suitable for a moderately intensive hydrological study. Further, the fact that the drainage basin is characterized by a relatively uniform relief, vegetation and climate has been a great asset in selecting the Sturgeon River basin for the present study. However, variations in the above mentioned factors occur within the drainage basin and have been discussed in the following sections of the thesis.

Data of several kinds used in this research were readily available from various published sources. In particular, long term hydrometric measurements made in the Sturgeon watershed and the availability of climatic data close to the drainage basin outskirts were helpful in the selection of this drainage basin.

Last but not the least, the active research interest of the Water Resources Divison of the Government of Alberta in various aspects of hydrology was also taken into account; government reports provided information which was not available otherwise.

METHOD OF INVESTIGATION

Meterological stations with a relatively long period of record were selected close to the drainage basin boundary; stations within the basin failed to meet this requirement. Temperature and precipitation data published by the Department of Transport, Meteorological Branch, were exclusively used for Edmonton Namao Airport, Fort Saskatchewan, Sion, Peavine, Edson and Moon Lake (Figure 6). Edson,

approximately 50 miles west of the drainage basin, could not be shown at the given scale. Long term temperature and precipitation data for Sion (1911-), Edson (1929-), and Peavine (1944-) are available. Similar data for the remainder of the selected stations are usually available for less than 15 years. A compromise was made between the long term and short term data by considering only a ten year period between 1960 and 1969.

Mean temperature and precipitation for nearly all the stations mentioned above were found to be incomplete for the years mentioned above. To overcome this problem, data obtained by forestry experimental stations within the drainage basin were also considered. Most of these stations have been in operation for the last 5 to 7 years and report temperature and/or precipitation for the summer months. Mean monthly temperature and precipitation values were computed by the method of interpolation for those selected stations which had incomplete data for the period considered. In so doing two assumptions, in the absence of detailed information, were made: (a) effect of relief on temperature is negligible so that temperature variations from station to station are essentially uniform and, (b) variations in precipitation do not occur randomly.

The major drawbacks in the assumption, however, are that the rainfall variations in summer months are generally erratic which may lead to an irregular rainfall distribution pattern from one station to another. Variations in mean monthly precipitation and temperature due to relief factors, may be considered negligible. However, snow drift during winter months may cause some change in total precipitation

accumulation on ground cover; a factor not considered in the assumption.

With the complete temperature and precipitation data now available, potential and actual evapotranspiration values were computed using the appropriate techniques (see Chapter II for the methods). Thornthwaite's method was further extended to determine the water surplus and water deficit patterns in the study area.

The results of potential evapotranspiration obtained by the application of methods mentioned above were compared among themselves. It must be pointed out that temperature and precipitation form the main matrix of Thornthwaite, Turc and Holdridge techniques. The main difference, however, is in the emphasis placed on precipitation or temperature or both.

Thornthwaite's method of computing evapotranspiration has gained a superiority over other methods of investigation and many researchers who have conducted research in the prairies and rest of Canada hold the technique as extremely useful in computing potential evapotranspiration and water balance (Laycock, 1967; Sanderson, 1950a; 1950b; 1954). Experimental data on potential evapotranspiration available from the Sturgeon watershed have been compared with the monthly PE values obtained by the Thornthwaite's (1948) technique. Actual evaporation values, obtained by the application of Thornthwaite and Turc methods, were also compared.

Finally, the water balance maps for the Sturgeon basin were also prepared to demonstrate water balance patterns in the study area.

DRAINAGE

Sturgeon River, Rivière Qui Barre Creek, Atim Creek and Kilini Creek constitute the principal drainage channels in the Sturgeon watershed. There is no dominant drainage direction; it is from west, southwest, north and northwest (Figure 2). These channels merge into Big Lake to form a main channel - Sturgeon River - which flows northeast to take a southeasterly course approximately 2 miles northeast of Gibbons.

Most of the drainage pattern in the study area is essentially an inheritance from a preglacial drainage system. Carlson (1967, Figure 4) has shown that parts of the main Sturgeon River flowed through the preglacial "Onoway Valley" forming a tributary to a "Beverly Valley" which had practically the same alignment as but slightly different course from the North Saskatchewan River northeast of Edmonton.

Within the basin there are four areas of internal drainage (Figure 2). Carl Primus[1] (personal communication) has suggested that in 19 out of 20 years there would be no overland flow from the areas of internal drainage mentioned above. These areas are significant hydrologically, in that the precipitation into local depressions evaporates directly and the remainder is available to streams as detention storage in the late spring and summer seasons.

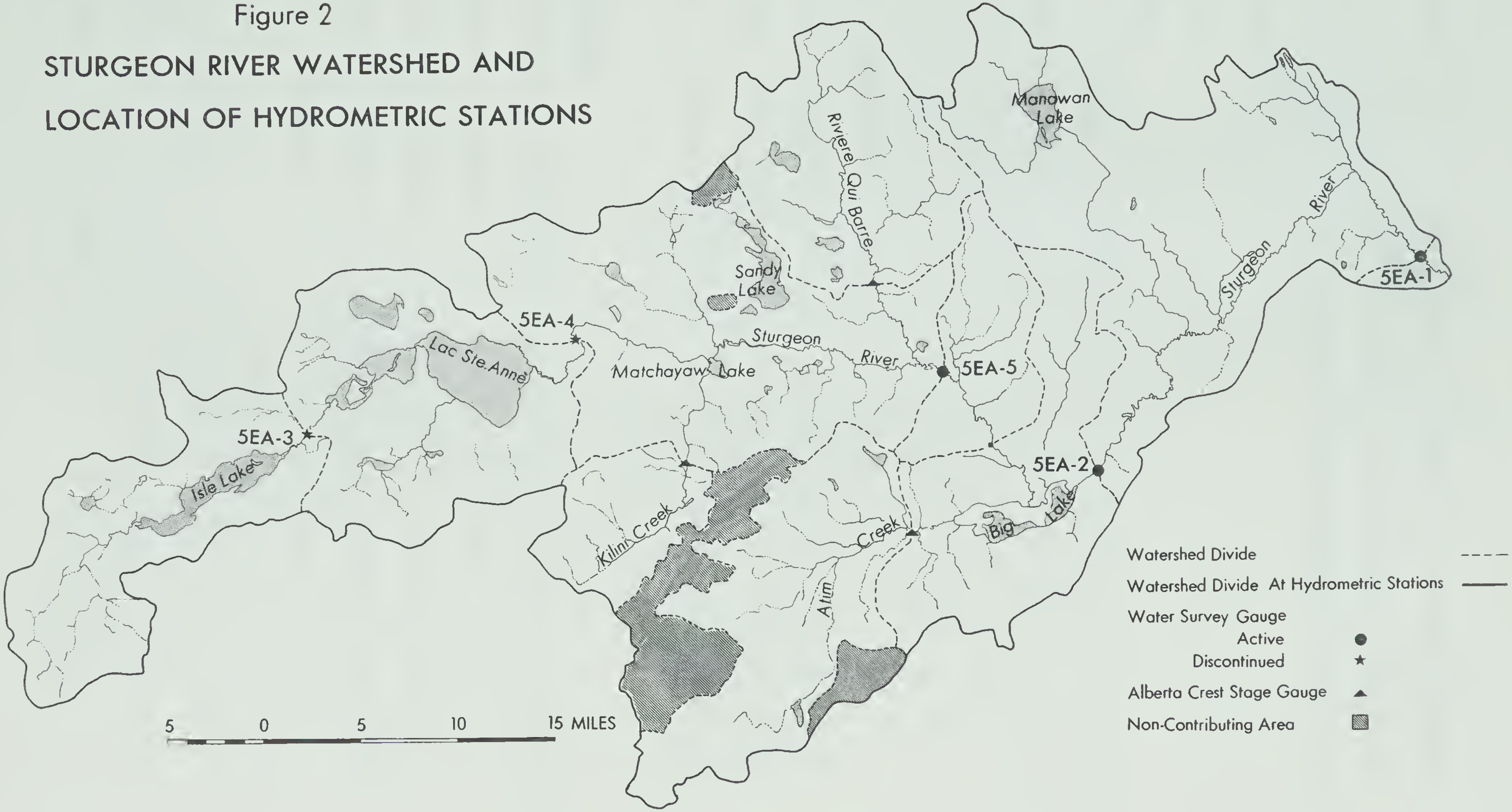
Over five per cent of the Sturgeon watershed is covered by lakes

[1]Mr. Primus, geographer, is attached to the Water Resources Divison of the Government of Alberta. He is currently engaged in a study of various aspects of the Sturgeon watershed.

Figure 2

STURGEON RIVER WATERSHED AND

LOCATION OF HYDROMETRIC STATIONS



of varying depth and by a large number of shallow swamps and sloughs. The lakes, as natural reservoirs, regulate the discharge through the main channels and hence tend to modify the hydrological characteristics of the drainage basin.

GEOLOGY

Bedrock geology:

Most of the study area is underlain by rocks of the late Cretaceous Edmonton formation. However, in the southwestern corner of the drainage basin the Paskapoo formation of Tertiary age outcrops in an area southwest of Isle Lake. The local bedrock exerts an influence on the mechanical composition of glacial deposits.

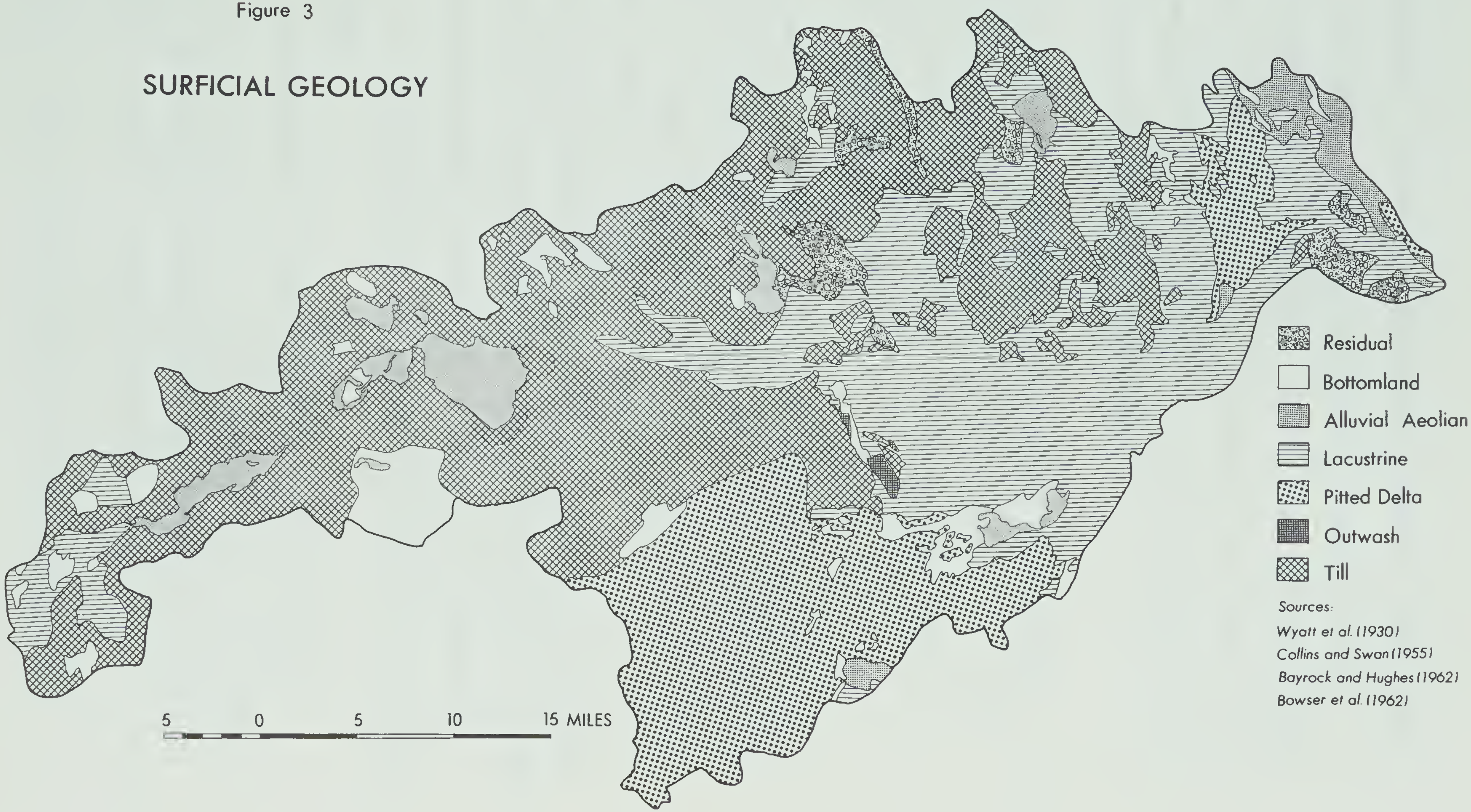
The Paskapoo formation is composed of sandstone and shales, with a few coal seams. The Edmonton formation is formed of silty to sandy brown and grey shales and shaly sandstone. Coal seams are frequently encountered.

Surficial deposits:

The surficial materials of the study area are largely lake deposits, deltaic deposits and glacial till. Of minor importance in the frequency of occurrence and areal extent are the bottomland deposits, aeolian and fluvial sands, kame deposits, outwash deposits, residual deposits and the Sturgeon river valley alluvium (Figure 3). The valley alluvium and the till crevasse fillings could not conveniently be shown on the map because of the limitations imposed by the map scale. The following categories of surficial deposits are known to occur within the Sturgeon basin.

Figure 3

SURFICIAL GEOLOGY



Bottomland deposits: This type of deposit is generally found under conditions of excessive moisture in topographic depressions and consists of unconsolidated, undecomposed to partly decomposed organic matter. Areas of this type varying in size from tens of square feet to more than one square mile are dotted all over the drainage basin. The largest of such areas is around Big Lake.

Alluvial aeolian deposits: Mapped in this category are deposits where part of the material that was originally deposited by moving water has been resorted by wind action. These deposits largely consist of fine to medium grained sand.

Lacustrine deposits: The Lake Edmonton deposits which largely occupy the eastern and central parts of the drainage basin consist of varved silts and clays ranging in thickness from less than one foot to over ten feet with an average of about five feet.

As shown in the accompanying figure, both 'normal' and 'modified' deposits are shown as the lake deposits. The normal deposits are those which were laid down under quiet-water conditions, not modified by later action. Ice-rafted pebbles and boulders are commonly encountered in these sediments.

Normal lake sediments which show post-depositional changes are termed as modified deposits. In the modified type of deposits, fluvial sand, representing deposition from the outflowing waters of the Lake Edmonton, commonly overlies the 'normal deposits'.

Deltaic deposits: Three isolated areas of deltaic deposits of

glaciofluvial origin occur in the Sturgeon basin. One such extensive area lies in the central southern parts of the drainage basin extending between the south of Big Lake to Carvel through Stony Plain and encompasses the southern undrained depressional land shown in Figure 2. The second area extends north-south through Bon Accord and, the third, of much smaller extent, parallels the Sturgeon River at the eastern margins of the study area.

The consideration of this unit as "Deltaic deposits" in the central southern region of the study area was primarily based on the information provided by the Soil Survey of the Edmonton Sheet by Bowser et al. (1962). Bayrock and Hughes (1962) mapped part of this area as "Early North Saskatchewan River alluvium", whereas Collins and Swan (1955) divided it respectively into "Beach sand and silt" and "Moraine-silt till in part bedded". The early North Saskatchewan River alluvium, according to Bayrock and Hughes (1962), is variable in thickness, usually up to five feet but at places reaches a thickness of about twenty feet. The alluvium is composed of fine to medium grained sand, silt, clay and, at places coarse sand and gravel is frequently encountered. The 'Moraine-silt till' unit of Collins and Swan (1955) presumably refers to 'silt till' or in other words, pitted delta (Warren, 1954). Describing their 'silt till' unit west of Kilini Creek, Collins and Swan (1955) state that in places the till includes layers of coarse stratified sands ranging in thickness from a few inches to more than ten feet. Beach sand and silt, an aforementioned unit, consist of poorly sorted medium to coarse grained sand with stratified layers of silt.

In the other two localities of the occurrence of this unit, the deposits are usually cross-bedded sands and silts (Bowser et al., 1962). Topographically these two areas are similar to the one described earlier and, to avoid much confusion and outdated terminology a term 'deltaic deposits' is tentatively assigned to this unit within the framework of detailed information provided by the Soil Survey Report.

Outwash deposits: Three areas of outwash deposits of glacio-fluvial origin are found around Gladu Lake. The deposits are mainly composed of moderate to poorly sorted gravel. However, inclusion of boulders, medium to coarse grained sand and till are not uncommon. Crevasse fillings, not shown in Figure 3, are about 10 feet high and 400 feet wide. They consist of poorly sorted gravel with numerous till and sand inclusions.

Till: Kame moraines, hummocky dead-ice moraines, and ground moraines have been included in this category. In this sense, they represent glacial till deposited under different geomorphic processes.

A report on the "Glacial geology of St. Ann area" by Collins and Swan (1955) shows some areas as interglacial sands, and bedrock exposed on the surface. Extensive field trips to these areas reveal that the mapped interglacial sand areas on the eastern margins of Lac Ste. Anne, around Onoway and, around Glenford are in fact overlain by till. A similar discrepancy occurs around Alexander Indian Reserve No. 134 and Sandy Lake. The surficial deposit in and around the Indian Reserve is very largely 'residual' in nature and, extensive till deposits commonly occupy the area around Deadman, Bard and Sandy

Lakes. It is, however, true, that bedrock is exposed on the surface within the topographic depressions only. Such depressions can not be shown on the given scale of the map. Furthermore, the cursory nature of field trips did not allow a detailed mapping of the bedrock exclusive of glacial till in this latter area. The above areas, therefore, have been mapped as glacial till.

The moraines are composed mainly of glacial till. Unsorted clay, silt, sand and gravel in various proportions constitute the bulk of sediment. The thickness of the deposits varies according to local relief within the moraines which at places may be 20 feet or more.

Residual deposits: Residual deposits are those in which the bedrock is near the surface and the overburden consists of a thin veneer of glacial, lacustrine, fluvial or aeolian sediments. Within the Indian Reserve, the bedrock is covered by a few inches of glacial and lacustrine deposits. Elsewhere, residual deposits display a similar nature.

TOPOGRAPHY

The existing topography (Figure 4) is essentially a product of the geomorphic processes operating in preglacial, glacial and post-glacial (Holocene) times. Preglacial topographic highs coincide with the present-day upland areas and the topographic lows generally coincide with preglacial trunk and major tributary valleys.

The absolute elevation varies from over 2,750 southwest of Isle Lake to little less than 2,000 feet at the mouth of the Sturgeon River giving approximately 750 feet of relative relief in the study basin. The differences in relief, apart from the bedrock elevation

and stream erosion, are largely due to the relative thickness of glacial deposits on top of the bedrock. Therefore, the topographic details may best be explained on the basis of the surficial geology of the area (Figure 3).

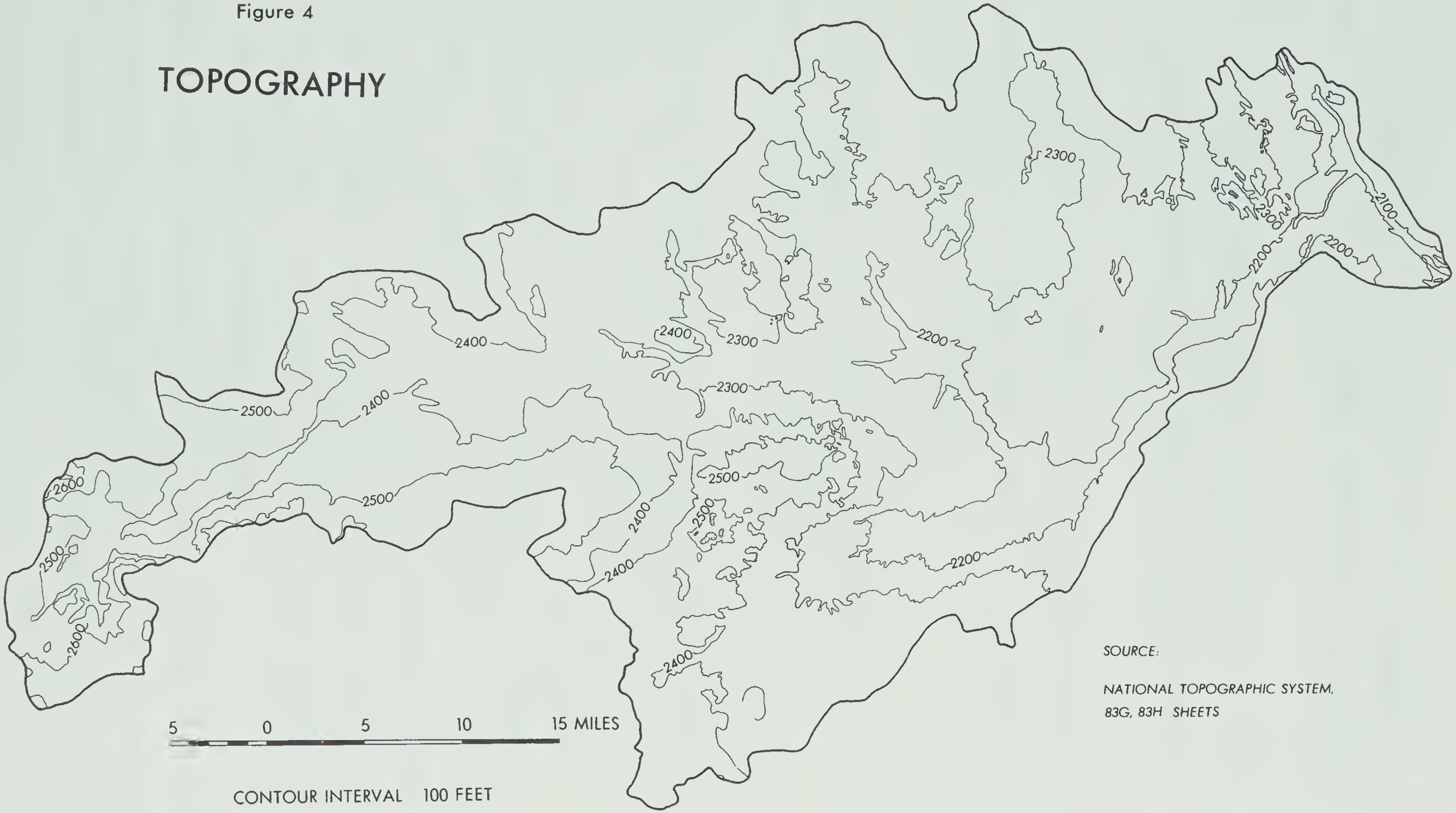
The distribution and relative thickness of the till sheets in the study area have been controlled largely by the differences in elevation of bedrock (Collins and Swan, 1955). It is for this reason that the above mentioned maximum altitude is found over till moraine extending southwest of Lac Ste. Anne. The maximum thickness of till in this area is close to 100 feet. Erosional processes during post-glacial times have modified the relief to a rolling topography. Many drumlinoid structures found to the south and southeast of Isle Lake give a rather undulating nature to the terrain. Lobate ridges and mounds are commonly encountered in this terrain. Several of the larger hummocks measure 500 feet by 200 feet and reach an average height of approximately 100 feet.

In the pitted deltaic region and particularly southeast of Kilini Creek swells and swales of smooth rounded forms are found in which small lakes or ponds develop during wet seasons. Surficial drainage from most of such depresssions is practically non-existent. The depressions may be as deep as 40 feet or more. The area located northwest of Atim Creek valley consists of small knobs up to 15 feet high. The intermediate area between the knobs is generally flat. The kettles tend to become smaller in magnitude towards the margins of the deltaic deposits.

The area of lacustrine deposits in the eastern and extreme western

Figure 4

TOPOGRAPHY



SOURCE:

NATIONAL TOPOGRAPHIC SYSTEM,
83G, 83H SHEETS

portions of the drainage basin have remarkably smooth topography. However, small areas of rolling to slightly undulating topography are not uncommon.

The areas of alluvial aeolian deposits (Figure 3) have a relief of 20 to 30 feet due to occasional depressions within longitudinal sand ridges.

Areas of residual deposits and areas around lakes make steeply sloping contacts with the adjoining areas. Relief in such cases varies from a few feet to more than 100 feet.

CLIMATE

A continental climate, designated as Dfc in the Köppen classification (Strahler, 1969), is characteristic of the area.

Temperature:

The mean annual temperature within the drainage basin ranges from about 35°F in the west to 36°F in the east (Figure 5).

The mean January temperature has a value of 2 to 5°F with the temperature gradient rising in a southerly direction. The maximum temperature during this month remains far below freezing (about 15°F). This is clearly indicated in Table 1. In February and March the mean temperatures show a rising trend throughout the study area. In April the mean temperature rises to about 35°F. As shown in the table the temperature rises sharply from winter to summer.

The summer season is long and relatively cool. The mean temperatures between May and September are above 50°F. July with a mean temperature of about 60°F is the warmest month of the year. By September the temperature begins to drop sharply and during October the mean temperature drops to about 39°F. In October a 10° to 15° drop from the previous month is not uncommon.

FIGURE 5

MEAN ANNUAL PRECIPITATION AND TEMPERATURE (1960–1969)

5 0 5 10 15 20

MILES

TABLE 1 - MONTHLY TEMPERATURE CHARACTERISTICS OF SOME METEOROLOGICAL STATIONS AROUND THE STUDY AREA[2]

Edmonton Namao A*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean daily temp.(°F)	5.6	10.4	21.5	39.3	52.1	57.3	62.9	59.9	51.4	41.2	24.6	13.6	36.6
Mean daily max. temp.	12.4	18.1	29.1	48.6	63.1	66.9	73.3	69.1	60.5	49.7	31.5	20.3	45.2
Mean daily min. temp.	-1.3	2.7	13.8	30.0	41.0	47.7	52.4	50.6	42.3	32.7	17.7	6.9	28.0
Maximum temperature	47.0	51.0	61.0	79.0	85.0	93.0	93.0	90.0	85.0	79.0	59.0	51.0	93.0
Minimum temperature	-33.0	-36.0	-31.0	3.0	19.0	34.0	42.0	35.0	23.0	5.0	-24.0	-33.0	-36.0
Edson													
Mean daily temp.(°F)	8.4	13.8	23.6	37.2	48.2	53.9	58.7	56.2	48.7	38.4	23.5	12.5	35.3
Mean daily max. temp.	18.7	26.1	35.9	50.2	62.3	67.5	73.0	70.6	62.6	51.2	33.4	21.5	47.8
Mean daily min. temp.	-1.9	1.4	11.2	24.1	34.0	40.2	44.4	41.8	34.8	25.5	13.6	3.4	22.7
Maximum temperature	55.0	66.0	72.0	86.0	90.0	98.0	100.0	92.0	88.0	84.0	69.0	62.0	100.0
Minimum temperature	-55.0	-48.0	-48.0	-30.0	8.0	25.0	25.0	25.0	-1.0	-14.0	-34.0	-54.0	-55.0
Peavine													
Mean daily temp.(°F)	6.9	12.3	23.4	39.2	50.7	55.9	61.2	58.4	50.6	40.8	24.6	12.6	36.4
Mean daily max. temp.	15.1	22.6	34.2	51.6	61.5	71.6	74.7	71.4	63.2	53.0	33.8	21.1	47.8
Mean daily min. temp.	-1.3	2.0	12.6	26.8	39.9	40.2	47.7	45.4	38.0	28.6	15.4	4.1	25.0
Maximum temperature	58.0	62.0	65.0	82.0	90.0	91.0	93.0	90.0	89.0	87.0	73.0	58.0	93.0
Minimum temperature	-53.0	-49.0	-39.0	-20.0	10.0	29.0	32.0	28.0	6.0	-8.0	-34.0	-40.0	-53.0

...19

Sion

Mean daily temp.(°F)	4.9	10.2	21.9	38.6	51.6	56.5	61.7	58.1	50.5	39.9	24.8	12.4	35.9
Mean daily max.temp.	15.7	22.0	32.8	50.7	65.4	70.4	75.8	72.0	63.6	52.1	34.4	22.3	48.1
Mean daily min.temp.	-6.0	-1.7	11.0	26.4	37.7	42.6	47.5	44.1	37.3	27.7	15.1	2.5	23.7
Maximum temperature	56.0	64.0	70.0	84.0	95.0	98.0	102.0	93.0	88.0	86.0	69.0	65.0	102.0
Minimum temperature	-61.0	-63.0	-40.0	-30.0	5.0	16.0	24.0	20.0	7.0	-15.0	-52.0	-58.0	-63.0

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2. Canada, Department of Transport, Meteorological Branch, Temperature and Precipitation Tables for Prairie Provinces, Vol. III, 1967, 56 pp. Met. Office, Toronto.

* The monthly temperature data for Edson and Sion are based on a mean period of 25-30 years. The Peavine data represent a ten year mean period whereas the Edmonton Namao A. data is for a mean period of less than ten years.

The November mean temperature for the study area is below 32°F and the temperature drops rapidly to a January minimum.

Variability of mean temperatures

In winters, springs and autums large variability of temperature is observed from year to year. However, summer temperatures in general and July temperatures in particular have remarkable uniformity from year to year. The variability of mean monthly temperatures for meteorological stations in Alberta with 25 years of record or more is given in the following table.

TABLE 2 - VARIABILITY OF MONTHLY MEAN TEMPERATURES (AFTER CURRIE, 1953)

Percentage of times when the temperature departed by	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10°	31	26	11	3	1	0	0	0	1	3	12	20
5°	61	57	41	26	9	4	3	3	12	21	46	50

As indicated by temperature values in Table 2 large departures of mean minimum temperatures occur more frequently in winter than in summer. This may be explained by the fact that the imports of warm Pacific air masses into this area tend to modify the effects of the cold, dense continental air masses.

The mean monthly temperatures for the selected stations are given in Appendix 2.

Precipitation:

The mean of 10 years precipitation for the Sturgeon watershed is shown in Figure 5. The mean annual precipitation varies from a little less than 15 inches in the east to about 19 inches in the west. This steep precipitation gradient may be due to inaccuracy of precipitation determination and other factors. Most of the precipitation is frontal, but the summer convectional showers play an important role in the distribution of rainfall over the area. Convectional precipitation is highly variable in intensity and duration from place to place. Immediate effects of high rainfall intensities are rapid runoff and soil erosion. Precipitation of this nature does not replenish the soil moisture to any considerable extent, and is thus partly wasted from this water balance viewpoint.

It is clear that the variability of monthly precipitation is greater than for the annual and seasonal cases. As might be expected small daily totals are far more frequent than large daily totals.

Winter rainfall from December through February is usually less than an inch. Rainfall equals about one inch in March and April. The mean May through September precipitation equals about eleven inches.

Mean annual snowfall varies considerably from year to year and from station to station. However, the variation in snowfall during winter months is not as large as for rainfall in summer months. The frontal precipitation of the winter months is wide-spread and, generally speaking, equally distributed through out the zone of cyclonic activity.

Within the study area mean aggregate snowfall varies from about 50 inches in the west to about 40 inches in the east. During winter

TABLE 3 - MONTHLY PRECIPITATION CHARACTERISTICS OF SOME METEOROLOGICAL STATIONS AROUND THE STUDY AREA [3]

Edmonton Namao A *	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug.	Sep	Oct	Nov	Dec	Year
Mean Rainfall(Inches)	0.01	0.01	0.03	0.04	1.57	3.30	2.93	2.17	1.32	0.51	0.11	0.08	12.44
Mean snowfall	9.40	7.60	8.30	7.40	1.10	0.00	0.00	0.00	1.30	5.00	7.70	8.20	56.00
Mean total precip.	0.95	0.77	0.86	1.14	1.68	3.30	2.93	2.17	1.45	1.01	0.88	0.90	18.04
Edson													
Mean rainfall (Inches)	0.02	0.02	0.07	0.38	1.97	3.59	3.66	3.16	1.48	0.37	0.17	0.09	14.98
Mean snowfall	9.80	7.30	8.80	6.80	0.80	0.00	0.00	0.00	1.50	6.10	8.60	9.00	58.70
Mean total precip.	1.00	0.75	0.95	1.06	2.05	3.59	3.66	3.16	1.63	0.98	1.03	0.99	20.85
# days with meas. rain	*	*	*	3	9	14	15	13	9	4	1	1	69
# days with meas. snow	7	6	5	4	1				1	3	5	6	38
# days with meas. precip.	7	6	6	7	10	14	15	13	11	6	6	6	107
Max. precip. in 24 hrs.	0.80	0.80	0.70	1.80	2.13	3.11	2.58	2.00	1.46	1.26	1.40	0.70	3.11
Peavine													
Mean rainfall (Inches)	0.00	0.00	T	0.16	0.61	4.07	3.14	2.96	1.20	0.08	0.02	0.04	13.28
Mean snowfall	10.20	9.60	12.70	11.80	8.10	1.10	0.30	0.40	4.00	9.30	9.40	7.60	84.50
Mean total precip.	1.02	0.96	1.27	1.34	2.42	4.18	3.17	3.00	1.60	1.01	0.96	0.80	21.73
# days with meas. rain	0	0	*	1	7	12	9	11	5	1	*	*	46
# days with meas. snow	5	6	7	6	3	1	*	*	1	3	5	5	42
# days with meas. precip.	5	6	7	7	8	12	10	11	7	4	5	5	87
Max. precip. in 24 Hrs.	1.40	1.20	1.90	1.60	1.75	2.96	4.10	3.16	2.10	2.25	1.60	0.90	4.10

Sion

Mean rainfall (Inches)	T	0.01	0.02	0.37	1.49	2.59	3.38	2.31	1.27	0.27	0.08	0.05	12.20
Mean snowfall	10.40	9.60	7.50	5.50	1.40	0.00	0.00	0.00	0.60	5.30	8.10	8.80	57.20
Mean total precip.	1.04	0.97	0.77	0.92	1.63	2.95	3.38	2.31	1.33	0.80	0.89	0.93	17.92
# days with meas. rain	*	*	*	2	6	10	12	10	7	2	1	*	50
# days with meas. snow	9	8	7	4	1				1	2	6	8	46
# days with meas. precip.	9	8	7	6	7	10	12	10	7	5	7	9	97
Max. precip in 24 hrs.	1.10	0.95	9,80	1.16	1.86	2.50	3.75	1.82	1.94	1.20	1.20	0.80	3.75

3. Canada, Department of Transport, Meteorological Branch, Temperature and Precipitation tables for Prairie Provinces, Vol. III, 1967, 56 pp. Met. Office, Toronto.

* The monthly precipitation data for Edson and Sion are based on a mean period of 25-30 years. The Peavine data represent a ten year mean period whereas the Edmonton Namao A. data is for a mean period of less than ten years.

FIGURE 6

LOCATION OF PLACE NAMES MENTIONED IN THE TEXT

months, the greater part of snowfall remains and accumulates on the ground. Ten inches of fresh snow is considered equivalent to one inch of rainfall. The terrain is flat to gently rolling and due to lack of any significant forest cover, except in certain virgin lands, melting of snow occurs rapidly over the drainage basin. This results in peak flows during the middle of spring (see Table 9, section on hydrology).

Mean monthly snowfall from November through January is about 30 inches with 10 inches experienced each month. About 6 to 7 inches of snow falls in February. Slightly more snowfall (8 to 9 inches) occurs in March with the April mean being about 5 inches. The details of the above discussion have been summarised in Table 3.

The total monthly precipitation of the six stations for a period of 10 years are given in Appendix 3.

SOILS

Within the study area soils of five major orders occur. These orders are classified as Chernozemic, Solonetzic, Podzolic, Rogosolic and Gleysolic. The textural classification is , however, of greater significance in this study area than the taxonomic classification. The soil classification by surface textures is shown in Figure 7.

Mineral soils range in texture from clay to sandy, largely in response to variations in parent material (Figure 3). The coarse textured soils coincide to a large degree with alluvium and dune sands, and are mostly classified as regosols. Silty clay loams occur primarily in areas of lacustrine deposits. These areas are frequently poorly drained and are classified by gleysols and humic gleysols. Other textural classes occur in all the three soil groups named. Also present are areas of predominantly organic soils which would be

classified as fibrisols, mesisols and humisols.

Such a classification is valuable in the context of water balance, as the capacity of a soil to hold moisture is largely dependent on its textural characteristics. Soil moisture storage values of some soil texture classes are given in the following table (after Colman, 1948).

TABLE 4 - SOIL MOISTURE CONTENT IN INCHES OF WATER/FOOT OF SOIL DEPTH

Soil Texture	At pore saturation	Detention storage	Moisture holding capacity	Retention storage	At Wilting point
Sand	5.0	4.1	0.9	0.5	0.4
Sandy loam	5.0	3.2	1.8	1.1	0.7
Loam	5.0	2.3	2.7	1.6	1.1
Clay loam	5.4	2.0	3.4	1.7	1.7
Clay	5.4	0.4	5.0	2.5	2.5

Field capacity (F.C.), permanent wilting point (P.W.P.) and available water capacity (A.W.C.) values for soils of the Edmonton Sheet were analysed by Verma (1968, Table IV). These values applicable to the soils of the study area are given in Table 5.

TABLE 5 - FIELD CAPACITY, PERMANENT WILTING POINT AND AVAILABLE WATER CAPACITY VALUES FOR SOILS OF THE EDMONTON SHEET APPLICABLE TO THE STUDY AREA

FIGURE 7

SOIL SURFACE TEXTURES

TABLE 5(cont.)

Soil order	Soil type	F.C.	P.W.P.	A.W.C.
		Inches of water in upper four feet of soil profile		
Chernozemic	Angus Ridge Loam	15.5	7.6	7.9
Chernozemic	Malmo Silty Clay Loam	18.9	9.7	9.3
Chernozemic	Mico Silty Clay Loam	23.6	11.1	12.5
Chernozemic	Navarre Silty Clay Loam	18.0	9.3	8.7
Chernozemic	Peace Hills Coarse Sandy Loam	7.5	3.3	4.2
Chernozemic	Ponoka Loam	17.2	7.5	9.7
Chernozemic	Winterburn Loam	14.3	5.7	8.6
Gleysolic	Prestville Silty Clay Loam	23.2	13.7	9.5
Podzolic	Cooking Lake Loam	18.2	8.4	9.8
Podzolic	Culp Loamy Sand	3.2	1.5	1.7
Podzolic	Leith Sandy Loam	5.7	2.1	3.6
Solonetzic	Wetaskiwin Silty Clay Loam	17.0	8.0	9.0

Field capacity, also referred to as the field-carrying capacity, normal field capacity, normal moisture capacity or capillary capacity, is the amount of water retained in the soil profile after excess water has been drained out under the force of gravity through macro pore spaces. Field capacity of a given soil is dependent largely on its texture. Thus sandy soil has a low field

capacity whereas silt and clay soils respectively have progressively higher field capacities.

Wilting point or wilting coefficient is determined by the quantity of soil moisture below which plants will be unable to extract further moisture from the soil and the foliage will wilt. This stage of soil moisture is called the critical moisture. If soil moisture is not maintained at this time by some external source of water supply the plants will die. Permanent wilting point is the determination of wilting point for a soil when the plant top is in a humid, not too hot atmosphere.

The difference between field capacity and wilting point is designated as the plant available water. For a field soil it refers to the total amount of water that can be used or removed from soil in support of higher plants (Peters, 1965). Some of the available moisture in this region is detention storage, much of which is replenished by precipitation received in frequent but light storms within the growing season.

Most authorities believe that only the water present in the upper 1-2 feet of the soils is readily available to cereal plants, the roots of which are concentrated in this zone. Many tree and grass species do use moisture from appreciably greater depths. Within the drainage basin, where Solonetzic soils occur, drainage is restricted by a hard clay pan horizon of low permeability, which restricts both moisture movement, and sometimes root development.

VEGETATION

Most of the study area is under cultivation. However, pockets of virgin land which still exist are characterised by 'pre-settlement' vegetation cover conditions.

Broadly speaking, there is a gradual change from open parklands in the east to boreal forest cover in the west of the drainage basin. Moss (1955) defined parkland as a broad tension belt between the prairie association of the semi-arid southeast portion of Alberta and the poplar association of the sub-humid northwest.

The eastern portion of the study area is characterised by Black and Dark Gray soils formed under a dominantly grass vegetation of rough fescue (Festuca scabrella). The trees are mainly aspen poplar (Populus tremuloides) in the better drained sites and balsam poplar (Populus balsamifera) in the poorly drained sites. Moss (1955) suggests that these trees were established in comparatively recent times. Periodic forest fires in the prairie, related directly and indirectly to drought and other patterns, were a deterrent to the establishment of trees.

The aspen species are gradually replaced by the conifers in the western parts of the study area. The dominant species in this part are white spruce (Picea glauca), black spruce (Picea mariana), Jack pine (Pinus banksiana) and lodgepole pine (Pinus contorta latifolia).

Throughout the study area there are many depressions generally covered by sphagnum moss. Labrador tea (Lendum groelandicum) is the principal shrub growing in the bogs. Black spruce (Picea mariana), tamarack (Larix laricinia), willow, dwarf birch (Betula glandulosa) and alder (Alnus spp.) grow around the edges of the bogs.

HYDROLOGICAL DETAILS

At the present time three hydrometric stations in the Sturgeon watershed are engaged in careful measurement and recording of stage and discharge along various reaches of the Sturgeon River (see Figure 2). Miscellaneous measurements were made at most of these stations in 1913, the first year of operation. Two hydrometric stations near Darwell and Onoway were in operation until 1931. All stations reported intermittent operation for some specific years. However, since 1968, the existing stations have shown continuous record without any break in operation.

TABLE 6 - HYDROMETRIC STATIONS WITH GAUGE LOCATION, DRAINAGE AREA AND PERIOD OF RECORD

St. No.	Name	Gauge location	Drainage area (sq.m.)	Period of record
5EA-1	Sturgeon River near Fort Saskatchewan	53°47'15" 113°13'20"	1,310	1914-23 1927-31 1935-
5EA-2	Sturgeon River at St. Albert	53°38'00" 113°37'21"	1,005	1913-27 1914-15 1928-30 1968-
5EA-3	Sturgeon River near Darwell	53°41'00" 114°35'00"	117	1914-15 1928-31
5EA-4	Sturgeon River near Onoway	53°43'58" 114°16'17"	269	1914-15 1928-31
5EA-5	Sturgeon River at Villeneuve	53°39'27" 113°45'40"	682	1914-15 1928-30 1968-

These stations are manually operated between the months of March and October inclusive. From November through February, temperatures

well below freezing inhibit any significant stream flow. Table 7 shows that the annual peak flows generally occur after the first week of April (see also Figure 9).

TABLE 7 - PEAK FLOW VALUES-STURGEON RIVER
NEAR FORT SASKATCHEWAN

Year	Annual Peak (cfs)	Date of Peak
1960	497.0	April 10
1961	666.0	March 30
1962	889.0	April 24
1963	621.0	April 27
1964	373.0	April 21
1965	1310.0	July 11
1966	1300.0	April 6
1967	792.0	May 1
1968	301.0	March 14
1969	649.0	April 11

This supports an earlier suggestion mentioned in a section on climate, that the snowmelt, caused by a sharp increase in temperature from winter to summer, occurs practically simultaneously over the drainage basin. However, in minor cases, an early increase of temperature during March (1961 and 1968) may also result in substantial increase in stream discharge. Similar increases may also coincide with thunderstorms in summer. High intensity and duration of a large number of storms that provided well above normal precipitation in June and early July following a large soil and surface moisture build-up in spring, most probably caused the peak flow on July 11, 1965.

which surpassed snow melt peak discharge in April.

Figure 8 shows the frequency curve of annual maximum daily discharges beginning from 1914.[5] Probable hydrologic events within the watershed are shown in the accompanying table.

TABLE 8 - PROBABILITY OF MEAN DAILY DISCHARGES [6]

Probability (per cent)	Mean daily discharges (cfs)
50	150
5	650
2	900
1	1,100

Crest stage gauges to determine the stage of water flow were established at Atim Creek near Spruce Grove, Rivière Qui Barre near Rivière Qui Barre and Kilini Creek near Heatherdown in the Sturgeon watershed. Station rating curves can be used to convert a record of stage into a record of discharge, but hydrometric data to-date were not available to establish stage-discharge for a given station.

The mean monthly and mean annual discharge (cfs) of the Sturgeon River near Fort Saskatchewan for a period of 1960-1969 are shown in Figure 9. The mean annual values tend to mask extreme monthly mean values. As shown in Table 9 mean monthly discharge between March and

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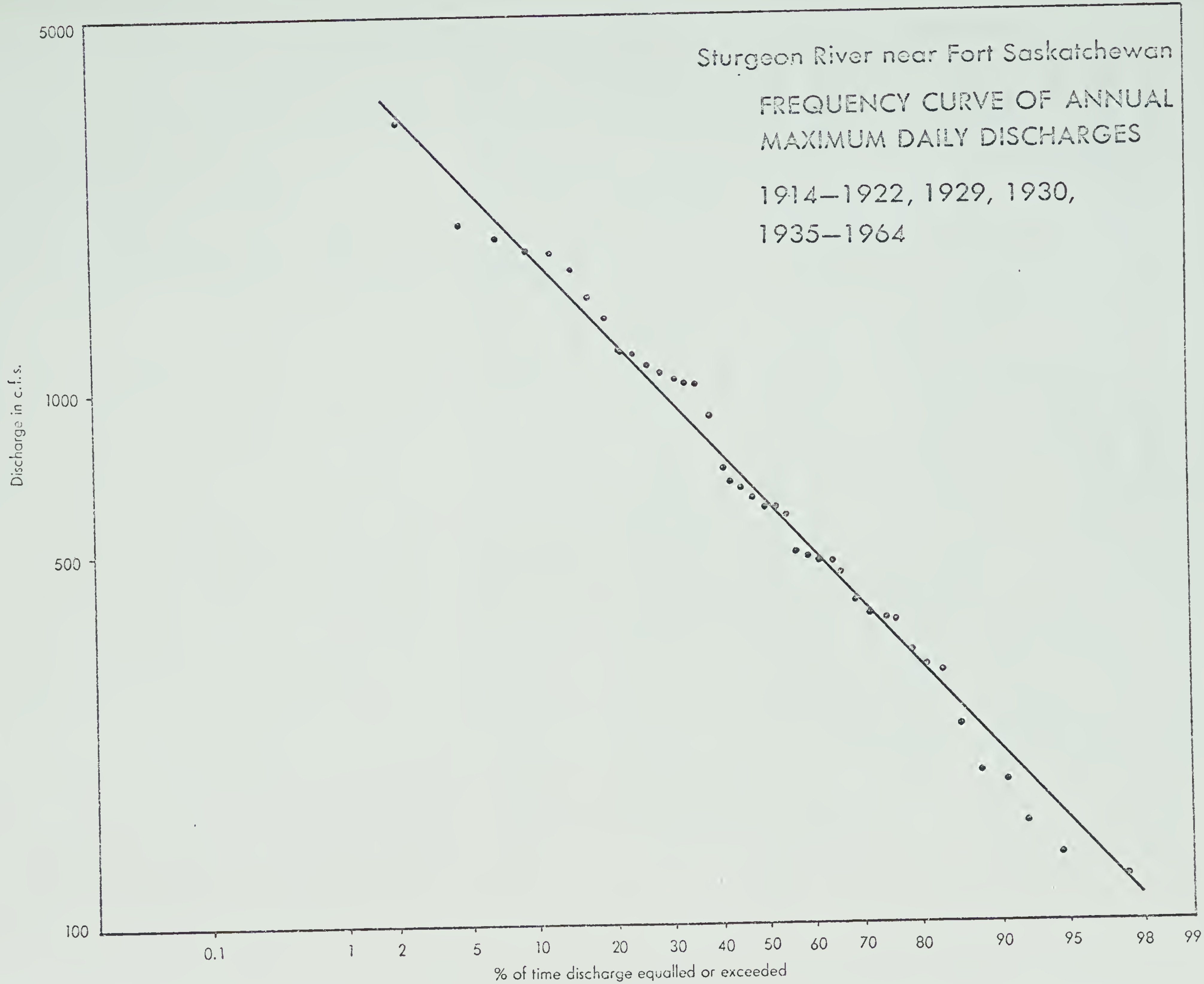
5. and 6. Alberta Department of Agriculture, Water Resources Division, Hydrology Branch: Available hydrometric data and background information, Sturgeon River hydrology report No. 1 (unpub.), 54 pp.

FIGURE 8


Sturgeon River near Fort Saskatchewan
FREQUENCY CURVE OF ANNUAL
MAXIMUM DAILY DISCHARGES
1914–1922, 1929, 1930,
1935–1964
Discharge in c.f.s.
5000
1000
500
100
0.1
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
% of time discharge equalled or exceeded

October varies from zero to a maximum of 1040 cfs. April is the only month during which consistently heavy stream flows occurs due to snow-melt. The rest of the months show variable stream flows from one year to another. Discharge during these months is largely determined by the frequency and magnitude of rainfall intensity.

The mean annual discharge varied from a minimum of 35 cfs. in 1968 to a maximum of 433 cfs. in 1965. The figure of 433 cfs. was the maximum average discharge value recorded since 1949. A minimum value of 25.7 cfs. was recorded in 1950 although data were not available for 1952. A higher mean annual discharge in 1965 was due to higher rainfall intensity and duration during the spring and summer months. Further, most of the meteorological stations in the area reported above normal precipitation during this year.

Depth of run-off in inches of water (Table 10) has been used in the comparison of water balance for the stations studied.

FIGURE 9

HYDROGRAPH (1960–1969) OF THE STURGEON RIVER NEAR FORT SASKATCHEWAN

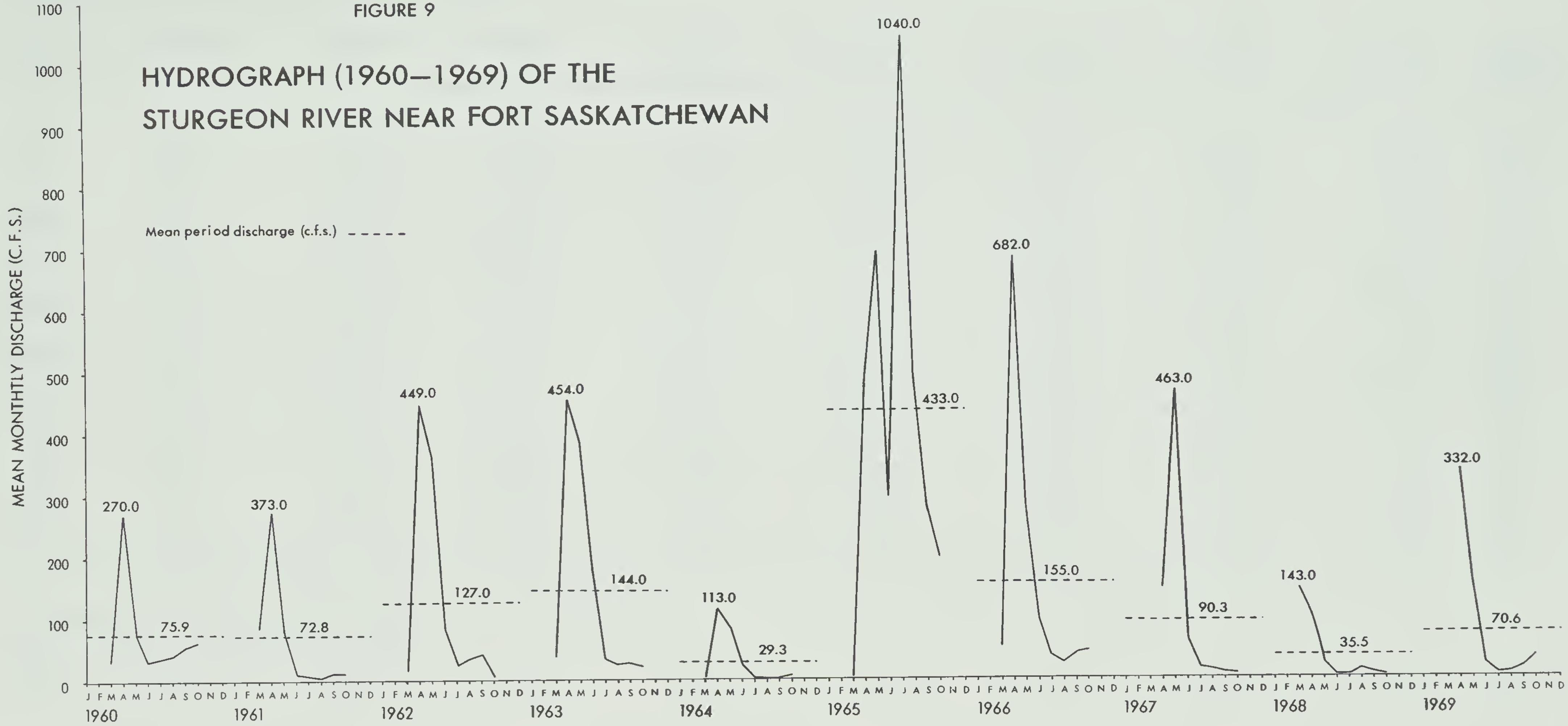


TABLE 9 - MONTHLY MEAN DISCHARGES, IN CUBIC FEET PER SECOND, FOR THE STURGEON RIVER (1960-1969) NEAR FORT SASKATCHEWAN, STATION# 5EA-1 AND STURGEON RIVER NEAR VILLENEUVE (1969), STATION# 5EA-5 .

Fort Saskatchewan, Station No. 5EA-1

Year	March	April	May	June	July	August	Sept.	Oct.	Mean (cfs)
1960	33.5	270.0	78.7	33.7	36.20	41.10	55.4	63.0	75.9
1961	84.2	373.0	80.6	11.1	8.69	6.98	12.4	11.6	72.8
1962	18.9	449.0	363.0	85.0	23.70	35.10	40.9	7.2	127.0
1963	39.5	454.0	383.0	176.0	33.70	24.70	27.2	21.3	144.0
1964	3.9	113.0	84.1	21.8	2.60	1.70	1.9	7.4	29.3
1965	3.0	476.0	691.0	298.0	1040.00	477.00	276.0	199.0	433.0
1966	51.6	682.0	281.0	94.3	30.80	25.10	40.8	45.9	155.0
1967	0.0	145.0	463.0	66.2	16.90	11.70	9.9	9.8	90.3
1968	143.0	99.2	21.0	2.0	2.00	10.90	4.1	2.0	35.5
1969	0.0	332.0	150.0	21.5	4.90	7.50	16.8	31.9	70.6

Villeneuve, Station No. 5EA-5

Year	March	April	May	June	July	August	Sept.	Oct.	Mean (cfs)
1969	1.8	273.0	11.0	1.6	0.72	40.6	43.3	15.2	48.4

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TABLE 10 - DEPTH OF RUNOFF IN INCHES FOR THE STURGEON RIVER MEASURED NEAR FORT SASKATCHEWAN (1960-1969), STATION NO. 5EA-1 AND STURGEON RIVER NEAR VILLENEUVE (1969), STATION NO. 5 EA-5.

Fort Saskatchewan, Station No. 5EA-1

Year	March	April	May	June	July	August	Sept.	Oct.	Total
1960	0.029	0.229	0.069	0.029	0.029	0.032	0.036	0.047	0.526
1961	0.074	0.317	0.071	0.009	0.008	0.006	0.010	0.010	0.505
1962	0.017	0.382	0.319	0.072	0.021	0.031	0.035	0.006	0.883
1963	0.035	0.386	0.336	0.150	0.093	0.022	0.023	0.019	1.064
1964	1.003	0.096	0.074	0.018	0.002	0.001	0.002	0.006	0.202
1965	0.003	0.405	0.607	0.253	0.914	0.419	0.235	0.175	3.011
1966	0.014	0.580	0.247	0.080	0.027	0.022	0.035	0.040	1.045
1967	0.000	0.123	0.407	0.056	0.015	0.010	0.008	0.009	0.628
1968	0.126	0.084	0.018	0.002	0.002	0.010	0.003	0.002	0.247
1969	0.000	0.282	0.132	0.018	0.004	0.007	0.014	0.028	0.485
Average	0.029	0.288	0.228	0.069	0.116	0.056	0.041	0.035	0.859

Villeneuve, Station No. 5EA-5

1969	0.002	0.460	0.017	0.002	0.001	0.064	0.073	0.024	0.643

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CHAPTER II

EVAPORATION, TRANSPIRATION AND EVAPO-TRANSPIRATION TERMS

An estimate of evaporation in general and evapotranspiration in particular is a problem of world-wide importance covering varied aspects of hydrology, climatology, agriculture and oceanography.

From a hydrological viewpoint the relationship between precipitation and runoff is perhaps the most important aspect studied by most physical hydrologists. More (1967) indicates the dependence of this relationship on other factors of the hydrologic cycle which are still only partially understood. In its simplest form the water yield of a drainage basin, including surface runoff and ground water flows, is precipitation over the watershed minus the losses from (a) evaporation from water bodies in the basin including snow and ice, (b) evaporation from land surfaces and, (c) transpiration by vegetation according to seasons, temperature and nature of vegetation.

Climatologists are most frequently interested in the balance between the income of water from precipitation and outflow of water by evapotranspiration. It is a climatic balance since the quantities precipitation and evapotranspiration are active factors of climate (Thornthwaite and Mather, 1957).

Agriculturalists primarily focus attention on the consumptive use of water by various crops. Oceanographers view the problem from an interdependent set of various components of the hydrologic cycle from the standpoint of two way transfer of energy across the atmosphere-ocean interface.

Evaporation may be defined as a process whereby water in liquid or solid state is transformed into gaseous form through the action of heat energy. This transfer of heat energy over plant-covered land surfaces is jointly controlled by complex climatic, soil and vegetation relationships. Without getting involved in the subtlety of complex interactions, an attempt has been made in this part of the chapter to study evaporation processes in their own merit. Evaporation involves four dynamic processes occurring simultaneously and comprising the following:

(1) percolation of water through the soil profile into the zone of absorption around plant roots, and its vaporization by radiation, conduction or convection, with conversion of energy into latent heat of vaporization,

(2) movement of water through plant tissues to the green stem and foliage and its removal by transpiration,

(3) direct evaporation of intercepted precipitation over outer plant surfaces and,

(4) removal of water vapour by turbulence, molecular diffusion and eddy motion from the evaporating surface.

There are some fundamental differences in the manner in which evaporation occurs over free-water and land surfaces; the most important being the availability of water at the surface. Other factors of equal importance may be thermal diffusivity, heat storage factor, heat conductivity and heat capacity of the two media. It is, therefore, desirable to study separately evaporation over free-water surfaces and land surfaces.

Evaporation from land surfaces:

The evaporation from land surfaces depends on the availability of water at the surface and incoming solar radiation. When the moisture content of the surface soil becomes limited the loss of moisture by surface evaporation practically ceases. Thornthwaite and Mather (1955b) report that extensive series of micro-meteorological measurements taken from Nebraska suggest that when the soil is very moist, more than 80 per cent of the net radiation is used in evaporation. However, when the soil is dry, evaporation is greatly reduced and most of the net radiation is consumed in heating the air. Veihmeyer (1964) maintains that when the moisture supply in the soil is limited, the evaporation from soil continues as long as moisture is present in the upper 4 inch layer in clays and 8 inch layer in sand and that, if precipitation or irrigation is of the nature to keep this layer moist at every time, the evaporation may be 100 per cent of the total available moisture to the soil. The rate of evaporation from an unsaturated soil, therefore, depends on the frequency of rewetting of the surface either by precipitation or irrigation methods.

The most important aspect of soil moisture is not the content but the rate at which water can move to the plant roots or the soil surface (King, 1961). Soil factors determine the rate of transpiration only when the moisture level in soils drops well below field capacity. The effect of soil moisture tension on evapotranspiration rates was studied by Makkink and Van Heemst (1956). They report that in a peat soil the effect of soil moisture tension on the reduction in evapotranspiration was smaller than in a clay soil.

The Russian scientists sought to understand the relationship between the ground water level and evapotranspiration on different soil types. The following table, compiled from Chebotarev (1966, p.87), clearly shows the dependence of evaporation on the availability of water in the surface layers.

TABLE 11 - EVAPORATION AND AVAILABILITY OF WATER IN SURFACE LAYERS

Groundwater level (inches)	Soil type	Evaporation compared with a free-water surface taken as 100%
6	Sandy, Clayey	90%
6	Loamy	48%
4	Clayey on rich vegetation	85%
10-12	Not indicated	30%
30	Not indicated	10%

Evaporation from soil or land surfaces cannot be divorced from transpiration and hence a more detailed explantion of evapotranspiration will be presented at a later stage of investigation.

Evaporation from snow, ice and water bodies:

Over five per cent of the Sturgeon watershed is covered by lakes of varying depth and a large number of shallow swamps and sloughs also exist. In this sense, evaporation estimates from snow, ice and water bodies in the study area assume vital importance. However, quantitative data for the study area or for that matter in central Alberta are not available to document this viewpoint. This discussion,

therefore, is nothing more than a summary of evaporation processes and in some cases observed rates of evaporation in different areas.

Evaporation from snow and ice:

Evaporation from snow covered surfaces, caused by the process of sublimation is of utmost importance in determining stream flow from those watersheds where the ground is snow-covered for several months of the year.

Evaporation from snow and ice surfaces occurs only when the vapour pressure of the overlying air is less than that of the snow surface. As the temperature rises above freezing, the rate of snow-melt exceeds the rate of evaporation. Williams (1961) has shown that during spring, about the same amount of energy is used in evaporating ice as in its melting and that net radiation is equal to, and in phase with, evaporation. Diamond(1953), however, showed that the amount of energy in melting of snow is usually much greater than the energy used in its evaporation.

Evaporation studies in U.S.S.R. (Chebotarev, 1966, p.86) indicate that the average depth of evaporation from an old snow pack is 3.5 times higher than from freshly fallen snow and that evaporation from open fields during snow-melt is three times higher than evaporation in snow field covered with vegetation.

Wind is considered to be an important meteorological factor affecting evaporation from snow and ice surfaces. Evaporation develops particularly intensively in the presence of strong, dry and cool winds. Croft (1944) found that the most important factor influencing the rate of evaporation from snow is air movement. He also suggested that in forested catchments, planned cutting of trees would control

wind movement. As a consequence, this would cut down evaporation rates in snow fields covered with vegetation and hence increase surface run-off by snow melt.

Most authorities agree that evaporation losses from snow and ice are only a minor fraction of the total evaporation losses from water bodies.

Evaporation from water bodies:

Evaporation from water bodies or free-water evaporation is largely controlled by climatic factors. Heat conductivity and also heat storage factors are the internal characteristics unique to individual water bodies. These characteristics are determined by such factors as shape, size, depth and relative situation of the water surfaces.

Transpiration:

Water in plants may be lost to the atmosphere by stomatal transpiration, cuticular transpiration and guttation.* But by far the greatest source of water loss in a plant is the stomatal transpiration. Veihmeyer (1964); Warrington (1900; Penmann, 1963) all agreed that the "transpiration of water by the plant is a part of its life-function, and is indeed to a certain extent proportional to the amount of growth". It must, however, be understood that transpiration is not in itself a measure of plant growth since the water requirements of plants are affected by the plant food available in the soil.

"Since the loss of water from plants is governed by the difference

* Guttation is the process whereby water is forced out of the plant through special organs called hydathodes. This process occurs when the transpiration is at a low rate.

in the vapour pressure in the space below the stomata and that of atmosphere, the aqueous vapour-pressure deficit of the air is the principle cause of transpiration"(Veihmeyer, 1964,p. 20). Other factors that influence the vapour pressure differences between the foliage and the air are the leaf structure, leaf area, and the relation of leaf to the neighbouring leaves. Also noted by other investigators (Watson, 1956; Penman, 1963) are the qualitative facts that with an increase in the ratio of foliage area/ground area, the transpiration increases proportionally with growth in the initial stages of plant growth and gradually attains a constant value when the leaf area/ ground area ratio (leaf-area index) becomes 2 or 3.

A more detailed discussion of evapotranspiration which follows in the next section of the chapter will attempt to correlate evaporation and transpiration with other meteorological and soil variables.

Evapotranspiration:

Total evaporation of water from the soil surface and transpiration by vegetation is termed as evapotranspiration. A distinction has been made between actual and potential evapotranspiration. The actual amount of evapotranspiration depends mainly on the availability of water, whereas potential evapotranspiration (PE) is the maximum amount of water that could be evaporated from vegetation and land surfaces assuming an unlimited moisture supply in the ground.

Potential evapotranspiration:

The idea of PE is an expression of the fundamental 'energy balance concept'. "Its weakness is in the infinite complexities of the natural surfaces, which make generalizations hard to apply in specific cases"

(Thornthwaite and Hare, 1965, p. 168).

Penman (1956) defined PE as the amount of water transpired in unit time by a short green crop of uniform height. The crop completely covers the ground and is never short of water. However, this definition is limited to a short grass surface only. Van Bavel (1966) considers that potential evapotranspiration can be defined for any situation in terms of appropriate meteorological variables and of the radiative and aerodynamic properties of the surface. The limiting factor, however, is the soil moisture and when the surface is wet and imposes no restrictions upon the flow of water vapour the potential value is reached. This definition can be applied to any surface when the moisture supply in the ground is unlimited. Parmele (1968) has extended this concept to mean that the major differences in the evaporation from a free water surface, bare wet soil and a vegetative surface with non-limiting soil moisture are due to differences in surface radiative properties and aerodynamic transport characteristics of the layer through which water vapour moves away from evaporating surface.

Thornthwaite (1944, p. 687) who first popularized the concept of evapotranspiration, defined it rather loosely "as the water loss from a moist soil tract completely covered by vegetation and large enough for oasis effect to be negligible". Since on a regional scale transpiration rates from plants in various stages of development may be considered small, Thornthwaite (1945; Chang, 1959, p.24) assumed "potential evapotranspiration as independent of the character of the plant cover, of soil type and of land utilization to the extent that it varies under ordinary conditions". In 1948, Thornthwaite, expressed

PE as an exponential function of the mean monthly air temperature and applied a day length adjustment to correct the relation for season and latitude. Varying emphasis on one or other of the interrelated factors in the definition of the concept led Curry (1965, p. 13) to state that "when Thornthwaite first published his concept of potential evapotranspiration in 1948 it was practically ill-defined, and his quantitative definition gave no clue for elucidating the significance of the concept.".

Thornthwaite (1954) reexamined his concept and introduced a number of plant and climatic conditions. For example, albedo of the evaporating surface must be standard (0.22-0.25), the rate of evapotranspiration must not be influenced by the advection of moist or dry air and finally the ratio of energy utilized in evaporation to that in heating the air must remain essentially constant.

Thornthwaite and Mather (1955a) defined PE as the amount of water which will be lost from a surface completely covered with vegetation if there is sufficient water in the soil at all times for use of vegetation. Thornthwaite et al. (1958, p. 5) maintain this view point and stress that

> "The only standard measures of evapotranspiration are those from a large, vegetation-covered land surface with adequate moisture at all times. This condition defines <u>potential evapotranspiration</u> or <u>water need</u>; since moisture is not restricted, potential evapotranspiration is limited solely by available energy".

As a prerequisite, the rate of evapotranspiration is dependent on the moisture content of the soil. Therefore, for evapotranspiration to reach a potential level it is necessary to assure that surface soil does not dry below 'field capacity', otherwise the ratio of evaporation

heat loss to the total heat loss could not remain constant. This means that variation in natural vegetation or crop would have little effect on water loss provided water supply in the ground is unlimited. However, albedo characteristics of the vegetative surface will have some influence on evapotranspiration. Similar arguments may also apply to soil-type. Also implied in the concept is that the water losses from a moist surface are determined primarily by meteorological factors.

Actual evapotranspiration:

Evapotranspiration occurring under natural conditions is dependent upon the available energy or the atmospheric demand.

Lemon et al. (1957) and Penman(1949) describe actual evapotranspriation as a function of soil, plant and meteorological factors. These factors have been mentioned in detail in an earlier section on evaporation and transpiration.

Actual evapotranspiration decreases with a decline in available soil moisture; a conclusion derived by Slatyer (1956) from experimental investigations in northern Australia. The above conclusion is also supported by Army and Ostle (1957) who analysed crop and weather data for over 25 years at two stations in the Northern Plains of Montana. They found that in years of high temperature and low rainfall, reduced crop growth and inadequate moisture supply resulted in low evaporation. Further, evaporation was always greater in fallow fields than in fields under continuous wheat crop.

Crop characteristics and the percentage of ground covered by crops also influence evapotranspiration. Tanner et al. (1960) describe the effect of the density of corn on evapotranspiration.

A corn field with high density per unit area intercepts more insolation than a field with low density crop resulting in lower transpiration from the latter field. The evaporation from soil, however, is primarily due to the energy reaching the soil surface. The evaporation from low density corn field will be higher thus partially making up for the difference in transpiration. It also follows that the length of time a crop is in foliage has an important effect on transpiration. The magnitude of evapotranspiration will also be expected to vary from corn, wheat, meadow, shrub and trees.

Supporting Leo and Shaw (1960) on the basis of his experimental studies, King (1961, p. 69) writes

> "If the number of plants per unit area is increased, then more of the energy will be intercepted by the plants; and very likely this will mean greater transpiration. It will also mean greater transpiration if the soil surface is dry. If the soil surface is moist there will be little change in evapotranspiration. In fact, after doubling the population of corn it was found (by Leo and Shaw) that the evapotranspiration for the season was slightly lower."

The response of evapotranspiration to plant growth was studied by Doss et al. (1962). They found that evapotranspiration by irrigated corn in Alabama increased with plant development to a maximum of 0.3 inch per day at dough stage and afterwords decreased with physiological activity of plant growth.

Ferguson (1965) studied weekly evapotranspiration by spring wheat in Manitoba. The evapotranspiration increased by 0.70 inch per week at the 3-leaf stage to 1.45 inch per week at the flowering stage and decreased to 0.60 inch per week as the crop reached maturity. Further, the actual evapotranspiration was correlated positively with

total rainfall plus the soil moisture storage.

During the summer months especially soil moisture supplies generally become depleted. Under such conditions actual evapotranspiration falls below potential evapotranspiration and is determined by the rooting habit of the plants, that is, the speed of movement of soil moisture to the plant roots.

Fulton (1966) gave conclusive evidence that during three consecutive seasons evaporation from bare soil amounted to 87.5 per cent of the total evapotranspiration from a potato crop in Ottawa. Moisture loss from the bare and cropped areas differed only for a short period of time at mid-season. This difference was attributed by the author to the fact that during this time plant roots utilized moisture stored at depths in the soil profile. This water was not available for direct evaporation. Later in the season when this moisture supply was depleted losses from the two areas again equalised.

BASES OF THORNTHWAITE, HOLDRIDGE AND TURC TECHNIQUES

Thornthwaite:

Thornthwaite (1948) proposed an empirical method of estimating potential evapotranspiration from mean temperature data. This technique is based on controlled lysimetric experiments and watershed observations of water loss in central and eastern United States. Potential evapotranspiration according to Thornthwaite's technique may be expressed by the following formula

$$PE = 1.6\ (10T/TE)^{a}$$

where PE = monthly unadjusted PE in cms.

T = mean monthly temperature (°C)

TE = annual temperature-efficiency (°C) and,

a is a cubic function of TE

The temperature-efficiency per month (i) can be better expressed mathematically as:

$$i = (ti/5)^{1.514}$$

where ti is the mean monthly temperature (°C). Similarly, a can also be expressed as:

$$a = (6.75 \times 10^{-7})\,(TE)^3 - (7.71 \times 10^{-5})\,(TE)^2 + (0.01792)\,(TE) + 0.49239$$

The expression for PE has to be adjusted for length of month and length of day. These values can be readily calculated from published tables or nomograms (Thornthwaite and Mather, 1957).

Limitations of the potential evapotranspiration concept have been pointed out by Halstead and Covey (1957), Lemon, Glaser and Satterwhite (1957), Change (1959), Pelton, King and Tanner (1960) and many others. The basic argument centres around Thornthwaite's assumption (1948) that the relationship between mean monthly temperature and mean monthly evapotranspiration is an exponential one. Later, Thornthwaite, Mather and Carter (1958) strongly argued that the ratio of the energy used in heating of the air to the energy devoted to evaporation varies with temperature, a fact empirically established. This means that solar radiation may be substituted by the mean temperature. Pelton et al (1960) state that "the error in using air temperature to estimate evapotranspiration is of the same order of magnitude as error in estimating net radiation from mean temperature. These errors

arise mainly from the energy stored in the soil and advection...". The mean temperature depends both on the net radiation and advective heat. Advective heat may be defined as the heat transferred from the air to the crop for use in evaporation when the air is warmer than a well watered crop.

Van Wijk and de Vries (1954) concluded from their studies in the Netherlands that methods based on mean monthly temperature do not give reliable results for different regions since given mean monthly temperature does not correspond to same evapotranspiration everywhere. Further, the temperature of the air lags behind solar radiation at moderate and high latitudes and, therefore, the amount of energy available for evaporation in spring is quite different from that available in autumn, if periods with same temperature are compared.

Van Bavel (1956) stated that the Thornthwaite formula lags three or four weeks in spring and summer because air temperature lags behind radiation which really determines evapotranspiration.

Halstead and Covey (1957) noted that the temperature and evapotranspiration are only empirically correlated and not related physically.

Mather (1959) stated that the Thornthwaite formula provides reasonably reliable values of potential evapotranspiration in humid areas. Where temperature and radiation are strongly correlated as in temperate, continental climates, the formula works well.

Holdridge:

While attempting to understand the relationships between the mountain vegetation of an area in Haiti and other vegetation units

of the island and surrounding regions, Holdridge (1947) developed a model for the classification of world plant formations upon a climatic basis. He visualised that the physiognomy and structure of plants in an undisturbed natúral vegetation environment reflects the integrated operation of climatic conditions through time.

This investigation later led to a paper entitled "Simple method for determining potential evapotranspiration from temperature data" in which Holdridge (1959) outlined the basis of his empirical formula for defining potential evapotranspiration from temperature data alone. Potential evapotranspiration from areas of natural vegetation was given as:

$$PE(mm) = [58.93 \text{ Unit period of time/No. of units of time in 1 yr.}] \times [\text{Comparative plant growth mean temperature } (^{\circ}C)] \quad \ldots.(i)$$

If the unit period of time is one year and the number of units of time in 1 year is 365 days then the equation (i) can be expressed as:

$$PE(mm) = 58.93 \text{ (Annual Biotemperature/365)} \quad \ldots.(ii)$$

where the subsequent mean annual Biotemperáture is defined as:

Mean annual Biotemperature = mean annual positive temperature in °C.

A satisfactory way of computing mean annual biotemperature (comparative plant growth mean temperature) followed in this research was by dividing the sum of the positive monthly mean temperatures by 12.

Holdridge (1959; 1960) defended the use of physiognomic variations in natural vegetation as the only criterion which provided a theoretical

basis for the formula he used to determine potential evapotranspiration.

1.) "The potential evapotranspiration rate at a given temperature decreases proportionally along the gradient of increasing precipitation from arid to wet areas, so that the product of evapotranspiration rate and the mean annual precipitation is the same all along the gradient. This is reflected in the regularity of the pattern of changes in physiognomy between the single climatic plant association of each of the formations along the precipitation gradient".

where the potential evapotranspiration rate is defined as the mean potential evapotranspiration in mm divided by the mean precipitation in mm.

2.) "Local variations in edaphic and atmospheric factors sufficient to cause an appreciable change in either evaporation, or transpiration, or both, are counterbalanced by the different physiognomies of the natural vegetation, developed in past through evolutionary processes, which bring the actual evapotranspiration into equilibrium with the potential evapotranspiration rate and the moisture available. These variations are reflected in the diversity of aspect and lack of regularity of pattern of changes of the physiognomies of the (usually several) edaphic, atmospheric and hydric association of the same plant formations along the moisture regime."

Noffsinger (1960) pointed out that a potential evapotranspiration formula based on temperature alone will be valid under very restricted conditions of insolation, humidity, and wind. In reply, Holdridge (1960) argued that the evolved physiognomic character of the natural vegetation is in fact an establishment of ecosystem in which differences in above mentioned factors will not be indicated.

Tosi (1964) reviewed and strongly supported the Holdridge Model for evaluating potential evapotranspiration. He reaffirmed that evapotranspiration is essentially a function of biotemperature (Tosi, p.179). Tosi also theorized that the biotemperature is strongly correlated with such latitudinally-related variables as the annual cycles of day-length and light angle, net radiation-intensity, thermal periodicity

and the proportion of the year during which critically low or below-freezing temperatures prevail.

The natural vegetation may be considered as an indicator of climate to the extent that it is not modified by edaphic (soil drought) or human factors. Further, it is assumed in the Holdridge Model that potential evapotranspiration is the amount of water which will be evaporated under constant optimal conditions of soil moisture and plant cover. In other words, the soil is always at the field capacity and covered by fully developed climax vegetation in the climatic association. Both these conditions are seldom, if ever, simultaneously satisfied in nature. Further, in recently glaciated areas, such as Canada, evolution of climatic climax vegetation may well be in progress and the present vegetation may represent sub-climax.

In many cases, the ecological requirements of some natural species may be the same but they react differently to climatic controls. For example, lodgepole pine and jack pine thrive as a result of fire and edaphic disturbance. However, lodgepole pine can stand a more rigorous environment and can tolerate a wider range of soil and moisture conditions than can jack pine. Because of these characteristics, lodgepole is not so good an indicator of climate as jack pine with respect to their respective climax domains.

Holdridge (1959) indicated that the plant growth is the same at -5°C or -55°C. This may be true, but the assumption that potential evapotranspiration is zero below freezing temperatures is invalid. Evaporation from snow-covered surfaces does take place, an objection, of course, that also applies to Thornthwaite's procedures.

Thompson (1966) applied Holdridge method to a mid-latitude mountain region, and studied the Grand division of the upper basin of Colorado river. He found that the Holdridge method can be used to estimate vegetation patterns and climatic factors in mid-latitude mountains. He suggested that separate assumptions should be made for winter and winter-free areas, since evapotranspiration from snow covered surfaces is not zero.

One of the greatest limitations of the Holdridge method is that it ignores definitive factors of climate that determine PE. The method emphasises a criterion that aids recognition of climate in an indirect way.

Turc:

Turc (1953) studied 254 drainage basins situated in Africa, America, Europe and Java for which long term precipitation, temperature and runoff data were available. From this data he was able to establish a formula to evaluate water balance in terms of precipitation and temperature.

Evaporation, given as precipitation (mm) minus runoff, was evaluated by the following formula:

$$\text{Actual Evaporation (mm) per year} \doteq P/\ 0.9 + (P/L)^2 \qquad \ldots.1$$

where P is the mean annual precipitation (mm); L is an increasing function of mean annual temperature (°C) and is given by

$$L \doteq 300 + 25t + 0.05\ t^3 \qquad \ldots.2$$

It is quite clear from equations (1) and (2) that actual evapotranspiration is a function of precipitation and temperature. Since

actual evapotranspiration is limited by available water supply two conditions may arise:

(1) When actual evapotranspiration is less than or equal to precipitation AE is a function of soil moisture availability until the latteris completely depeleted.

(2) In two areas of equal precipitation, actual evapotranspiration increases with temperature. However, actual evapotranspiration does not exceed evaporation from a free water surface with similar temperature conditions. In other words, actual evapotranspiration cannot exceed PE.

Formula (1) was developed in areas where mean annual temperature was less than 14°C. Turc (1953) claims that this method has proved satisfactory in arid, semi-arid, sub-humid and humid areas.

Not much published research is available on the application of Turc's technique of evaluating annual AE. Most research with Turc's method, however, has been with his detailed formula which estimates monthly PE values (Mohrmann and Kessler, 1959). Therefore, the reliability of this method to areas other than those studied by Turc is not known.

The reliability of Turc's formula is conditioned by the manner of precipitation and temperature distribution. In Algeria, for example, where precipitation is concentrated in winter, the formula underestimates AE during the same season.

The method is limited by the following consideration:

(a) Topographic and geologic factors influence evaporation in different and complex ways. These factors have not been considered in the formula.

(b) Turc does not consider soil moisture storage change, and soil moisture retention. These factors also affect water balance and the computed runoff.

(c) A further disadvantage as mentioned previously is that temperature and precipitation are not the only factors influencing evapotranspiration. For example, Carder (1961) has furnished evidence for an area in Northern Alberta which shows that in a 3-year free-water evaporation study, an evapometer tank in the open field lost 34.5 per cent more water than a tank sheltered by buildings and trees. Lower rates of evapotranspiration from the sheltered tank were largely due to low wind velocities and fewer daily periods of sunshine as compared to the evapometer tank in open field.

CHAPTER III

COMPARISON OF EVAPOTRANSPIRATION FOR THE STUDY AREA

Potential Evapotranspiration (Thornthwaite Versus Holdridge)

Thornthwaite:

Potential evapotranspiration values estimated by the Thornthwaite method for the Sturgeon watershed vary from slightly less than 19.5 inches in the west to little more than 21.0 inches in the east (Figure 10; Table 12).

Laycock (1967), using the Thornthwaite method but for a different time period, estimated potential evapotranspiration for the Prairie Provinces. The potential evapotranspiration for the Edmonton area varied from 20 to 22 inches. Further, he also showed that annual PE values in the Prairie Provinces show a decrease from south to north with some variations due to elevation in the western regions, and to the proximity of Hudson Bay in northeast.

Verma (1968) suggested that Thornthwaite's method slightly overestimated PE when compared to potential evapotranspiration values obtained by Penman's (1963) method for the Edmonton area.

Sanderson (1950b) concluded from her experimental studies that the results from Toronto evapometers verify Thornthwaite's method for computing PE at that latitude. Further, this technique neither overestimated nor underestimated PE for any one month or season during the three years of study.

Levine (1959) reviewed literature on estimating PE from various techniques and concluded that both Penman and Thornthwaite overestimate PE.

FIGURE 10

POTENTIAL EVAPOTRANSPIRATION (1960–1969), INCHES

TABLE 12 - COMPARISON OF POTENTIAL EVAPOTRANSPIRATION (INCHES)

Year	Holdridge	Thornthwaite
Edmonton Namao		
1960	15.47	21.22
1961	15.52	21.69
1962	15.38	21.48
1963	16.56	21.38
1964	15.06	21.65
1965	14.34	20.64
1966	13.99	19.58
1967	15.15	20.17
1968	14.06	19.90
1969	14.43	20.82
Average	14.99	20.85
Fort Saskatchewan		
1960	15.24	20.53
1961	15.24	21.83
1962	15.43	21.93
1963	16.77	22.13
1964	15.31	22.06
1965	14.78	20.98
1966	14.62	20.96
1967	15.45	21.67
1968	14.22	20.92
1969	15.08	21.53
Average	15.21	21.45

Table 12...

Year	Holdridge	Thornthwaite
Sion		
1960	14.04	19.44
1961	13.99	20.24
1962	13.59	18.87
1963	15.64	20.97
1964	13.97	19.72
1965	14.11	19.82
1966	13.55	19.09
1967	15.10	20.17
1968	12.81	18.42
1969	13.59	19.66
Average	14.04	19.64
Peavine		
1960	14.62	20.49
1961	14.55	19.96
1962	14.27	20.44
1963	15.33	21.51
1964	14.20	20.48
1965	13.92	19.82
1966	13.39	18.77
1967	14.75	19.76
1968	13.25	18.42
1969	13.48	19.84
Average	14.17	19.95
Edson		
1960	13.62	19.31
1961	13.78	19.43
1962	13.20	18.62

(cont.)

Table 12...

Year	Holdridge	Thornthwaite
Edson (cont.)		
1963	14.92	19.97
1964	12.50	17.61
1965	12.71	18.36
1966	12.27	16.89
1967	13.32	19.10
1968	11.95	17.68
1969	12.97	18.15
Average	13.13	18.51
Moon Lake		
1960	13.76	19.44
1961	13.80	19.87
1962	13.48	18.62
1963	13.92	20.04
1964	13.48	19.07
1965	13.18	18.12
1966	12.32	17.18
1967	13.69	19.04
1968	13.04	18.58
1969	14.38	19.94
Average	13.50	18.99

A comparison of the mean monthly PE for Sion is given in Table 13. For the months of May and June, Penman generally gave higher comparative PE values than estimated by Thornthwaite. Between July, August and September a reverse trend is clearly indicated.

Experimental data on PE from Fort Saskatchewan (Table 14) is here compared with the average potential evapotranspiration (1967-1969)

for June (4.21 inches) and July (4.93 inches) computed by the Thorntwaite formula. If the area covered by annuals and perennials is considered equal, the observed average PE for June and July months equals 3.93 inches and 4.37 inches respectively. This means that the Thornthwaite method gave values of PE for June and July months which were higher than the observed values by as much as 7 per cent and 12 per cent respectively.

The sources of discrepancies between Penman, Thornthwaite and observed PE are difficult to determine. Observation of PE under natural conditions is again a matter of using suitable and sensitive instrument for measuring PE. Mukammel (1961, pp. 84-105) described most commonly used evaporation pans and atmometers and discussed their characteristics, relative merits, representativeness and usefulness of observation from these instruments. He warned that none of the instruments discussed are liable to give accurate results under natural conditions since the hydrodynamic nature of moisture transfer from the surface to the atmosphere is not completely understood. Such conditions also apply to all the formula used in estimating PE.

The data presented in Table 15 do not apply specifically to any station studied in this research. However, a general comparison of the June data (Table 15) with the computed PE for June, 1968 determined by Thornthwaite indicates that all the stations studied showed lower estimates of PE. Edmonton Namao A. and Fort Saskatchewan showed a difference of about 1 per cent while the remaining stations showed

values 11 per cent lower than the irrigation gauge evaporation values. In the Edmonton area and the rest of the drainage basin west of 114° 00' Longitude, monthly and annual variations in temperature and precipitation alone reduce the applicability of these data to the Sturgeon basin.

Initial stages of experimental studies in the Sturgeon watershed do not allow more detailed comparative study of observed and computed PE on monthly or yearly basis.

TABLE 13 - COMPARISON OF MEAN MONTHLY POTENTIAL EVAPOTRANSPIRATION (INCHES) FOR SION (PENMAN[1] VERSUS THORNTHWAITE[2])

Year		Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Total	Total (May-Sept)
1960	1	---	3.4	3.5	4.5	2.7	1.8	---		15.90
	2	1.38	2.39	3.67	4.93	3.75	2.22	1.10	19.44	16.96
1961	1	---	3.5	4.6	4.0	3.5	1.4	---		17.00
	2	0.69	3.19	4.89	4.52	4.50	1.90	0.55	20.24	19.00
1962	1	---	3,1	3.9	3.3	2.7	1.6	---		14.6
	2	1.03	2.39	3.67	4.11	3.75	2.54	1.38	18.87	16.46
1963	1	---	3.3	4.9	5.3	4.0	2.2	---		19.7
	2	1.03	2.39	3.67	4.93	4.12	3.18	1.65	20.97	18.29
1964	1	---	4.0	4.9	5.1	3.5	1.6	---		19.1
	2	1.03	2.79	4.08	4.52	3.75	1.90	1.65	19.72	17.04
1965	1	---	4.1	4.3	5.0	3.6	1.5	---		13.5
	2	0.69	2.79	3.67	4.93	4.50	1.59	1.65	19.82	17.48

1. T.R. Verma, Moisture Balance in Soils of Edmonton Area. Unpublished Ph.D. Thesis, University of Alberta, Edmonton 1968, 204 pp. Verma computed PE for a number of Stations using Penman's technique (1963, p. 40). This technique may best be described as a complex effort requiring much more detailed meteorological data than any of the preceding methods described before. In this method PE is defined as a function of available radiant energy, saturation deficit and wind speed. Verma substituted radiation values obtained at Edmonton International Airport for Sion. Other variables mentioned above were computed by appropriate mathematical formulae.

Table 13...

Year		Apr	May	Jun	Jul	Aug	Sep	Oct	Annual Total	Total (May-Sept)
1966	1	---	4.9	4.4	4.4	2.9	2.2	---		18.8
	2	0	3.19	3.67	4.52	3.75	2.86	1.10	19.09	17.89
1967	1	---	3.7	4.1	4.6	4.0	2.9	---		19.3
	2	0	2.79	3.67	4.93	4.50	3.18	1.10	20.17	19.07

TABLE 14* - AGROMETEOROLOGICAL MONTHLY SUMMARLY FOR FORT SASKATCHEWAN (1967-1969 AVERAGE)

Month	Average ppt.(in)	Average evapotranspiration use (in)		Average crop consumptive moisture balance (in)	
		Annuals	Perennials	Annuals	Perennials
June	0.69	4.07	3.78	-3.38	-3.09
July	3.48	4.52	4.21	-1.04	-0.73

Source: Modified after Alta Dept. Agr., Water Resources Div., 1970.

TABLE 15* - SUMMARY DATA FROM IRRIGATION GAUGE PROGRAM - 1968, EDMONTON REGION

Month	Evaporation (cc of water)	ET(in)		PPT. (in)	Soil moisture balance (in)	
		Annual	Perennial		Annual	Perennial
June	1,840	4.41	3.81	1.72	-2.69	-2.09
July	1,543	4.32	4.02	2.80	-1.52	-1.22
August	952	1.71	2.73	2.26	+0.55	-0.11
Sept.	646	1.16	1.53	2.12	+0.94	+0.59
Oct.	123	0.25	0.30	0.00	-0.25	-0.30

Source: Modified after Alta, Dept. Agr., Water Resources Div., 1969

*The data represented in Tables 14 and 15 are collected in the field by using "gen atmometers". Dick Heywood of Agriculture Department, Govt. of Alberta (personal communication) has pointed out that two gen atmometers installed at the same place in Peace River country did not provide identical results and the disparity was fairly large. The instrument, however, is still in use because its reading does not require skilled personnel.

Smith (1965) applied a similar comparative technique for computed and observed PE in a humid British climate to evaluate Penman and Thornthwaite methods. He found that Thornthwaite's estimates of PE were higher by 23 per cent of measured tank evaporation. Penman, on the other hand, estimated PE which was lower by 16 per cent of the measured tank evaporation. Further, Thornthwaite's formula gave higher values of PE estimates in the summer season.

This generalization also seems to apply to the Sturgeon watershed.

Holdridge:

The mean annual PE computed by the Holdrige formula is given in Table 12 and its distribution for the study area diagrammatically shown in Figure 10. The above formula does not compute the mean monthly PE and hence only a general comparison between Thornthwaite and Holdridge is possible.

PE varies from about 13.5 inches to 14.5 inches in an easterly direction. A comparison of the data in Table 12 indicates that Holdridge's PE values were lower by 5-6 inches when compared to Thornthwaite. Despite the fact that the Thornthwaite formula gives lower or higher estimates of PE during the course of the year, it may be probable that the mean values are closer to those which occur in nature. Hence, the Holdridge method is singled out as not applicable to the study area in particular and the Prairie environment in general. A detailed discussion of the method has already been presented earlier in this research.

Actual Evapotranspiration (Thornthwaite (1948) Versus Turc)

Comparative data on actual evapotranspiration for the stations studied are given in Table 16. An average soil storage of 4 inches for the study area was considered the most appropriate value to estimate AE using Thornthwaite's method. It must also be pointed out that Turc does not bring in the soil moisture storage. An examination of this data indicates that Turc gives lower AE values than Thornthwaite. Figure 11 shows the distribution of actual evapotranspiration for the Sturgeon watershed. Actual evapotranspiration varies from about 16.5 inches to 14.5 inches decreasing in an easterly direction for the Thornthwaite method. Turc gives actual evapotranspiration values ranging from about 11.5 to 10.5 inches also decreasing in an easterly direction.

Experimental data on actual evapotranspiration in the study area are not available to-date. Therefore, a water balance approach was adopted to compare these two methods. If the total amount of total mean annual precipitation and total annual measured runoff are known for any one year they could be correlated with AE in the following manner:

$$\text{Ppt.} = S + AE$$

where Ppt. = mean annual precipitation

S = Stream runoff (Surplus)

AE = Computed actual evapotranspiration

Soil moisture is not a factor in Turc's formula and, therefore, the equation should roughly balance if this technique is applicable to the study area. Soil moisture and storage changes from year to year, important factors in Thornthwaite's technique, have not been taken into

FIGURE 11

ACTUAL EVAPOTRANSPIRATION (1960–1969), INCHES

5 0 5 10 15 20

MILES

account at this level of investiagation. Thus a slight deviation of the factor (S + AE) from precipitation value is expected. Computation of the data and results for Fort Saskatchewan and Sion are given in Table 17. The values of surplus (S) are taken from Table 10, Chapter I.

TABLE 16 - COMPARISON OF ACTUAL EVAPOTRANSPIRATION (INCHES)

Year	Turc	Thornthwaite (at 4 inch soil moisture)
Edmonton Namao A		
1960	12.21	19.53
1961	11.64	16.36
1962	9.96	14.87
1963	9.30	11.32
1964	10.99	16.33
1965	11.27	16.80
1966	9.95	14.82
1967	10.15	12.00
1968	10.27	14.76
1969	11.28	16.95
Average	10.70	15.37
Fort Saskatchewan		
1960	11.62	20.14
1961	11.16	15.54
1962	11.46	16.10
1963	7.57	8.41
1964	10.83	14.98
1965	10.72	16.41
1966	9.60	13.90
1967	9.01	9.81
1968	9.52	13.40
1969	10.57	14.98
Average	10.20	14.37

Table 16...

Year	Turc	Thornthwaite
Sion		
1960	11.67	16.33
1961	11.02	14.16
1962	12.27	17.55
1963	10.23	11.90
1964	12.70	16.99
1965	10.92	17.07
1966	10.28	15.17
1967	8.95	9.74
1968	10.62	16.20
1969	11.68	19.19
Average	11.03	15.40
Peavine		
1960	11.82	18.95
1961	12.03	18.20
1962	12.25	20.44
1963	11.57	15.09
1964	12.28	20.48
1965	11.20	17.29
1966	10.66	16.39
1967	8.57	8.24
1968	11.33	17.87
1969	11.32	19.03
Average	11.30	17.20
Edson		
1960	10.80	18.40
1961	11.69	17.59
1962	12.33	18.62
1963	11.52	14.69
1964	11.84	17.61

Table 16...

Edson (cont.)

Year	Turc	Thornthwaite
1965	12.76	18.36
1966	13.89	16.89
1967	10.36	12.58
1968	10.78	17.68
1969	11.40	18.15
Average	11.74	17.08
Moon Lake		
1960	11.06	19.33
1961	11.42	14.71
1962	11.02	18.62
1963	11.66	13.46
1964	15.03	19.07
1965	11.86	18.12
1966	10.34	16.23
1967	10.25	12.37
1968	10.40	15.97
1969	12.99	17.35
Average	11.60	16.51

For Fort Saskatchewan (1960-1969), Turc's mean annual AE showed a deficiency of 3.80 inches, while Thornthwaite at a 4 inch soil moisture storage value exaggerated AE by 0.37 inch from the expected AE values computed by the equation given above. Turc gave lower estimates of AE respectively by 8.33 and 1.25 inches for 1960 and 1967. However, in 1963 the formula computed actual evapotranspiration which was higher by 0.40 inch. Thornthwaite's method, however, showed much less variability from year to year between the computed and

TABLE 17 - COMPARISON OF AE AND SURPLUS WITH PRECIPITATION (INCHES)

Year	Ppt.	S	AE Turc	AE+S	± Diff	AE Thorn-thwaite	AE+S	± Diff
Fort Saskatchewan								
1960	20.98	0.53	11.62	12.15	+8.33	20.14	20.67	+0.31
1961	16.69	0.50	11.16	11.66	+5.03	15.54	16.04	+0.65
1962	17.43	0.88	11.46	12.34	+5.09	16.10	16.98	+0.45
1963	8.23	1.06	7.57	8.63	-0.40	8.41	9.47	-1.24
1964	15.98	0.20	10.83	11.03	+4.95	14.98	15.18	+0.80
1965	17.78	3.01	10.72	13.73	+4.05	16.41	19.42	-1.64
1966	13.69	1.04	9.60	10.64	+3.05	13.90	14.94	-1.25
1967	10.89	0.63	9.01	9.64	+1.25	9.81	10.44	+0.45
1968	12.05	0.25	9.52	9.77	+2.28	13.40	13.65	-1.60
1969	14.92	0.48	10.57	11.05	+3.87	14.98	15.46	-0.54
Average	14.86	0.86	10.20	11.06	+3.75	14.37	15.23	-0.37
Sion								
1960	19.28	0.53	11.67	12.20	+7.08	16.33	16.86	+2.42
1961	16.89	0.50	11.02	11.52	+5.37	14.16	14.66	+2.23
1962	19.81	0.88	12.27	13.15	+6.66	17.55	18.43	+1.38
1963	13.30	1.06	10.23	11.29	+2.01	11.90	12.96	+0.34
1964	21.82	0.20	12.70	12.90	+8.92	16.99	17.19	+4.63
1965	18.00	3.01	10.92	13.93	+4.07	17.07	20.08	-2.08
1966	16.21	1.04	10.28	11.32	+4.89	15.17	16.21	0
1967	10.96	0.63	8.95	9.58	+0.38	9.74	10.37	+0.59
1968	16.67	0.25	10.62	10.87	+5.80	16.20	16.45	+0.22
1969	24.80	0.48	11.68	12.16	+12.64	19.19	19.67	+5.13
Average	17.77	0.86	11.03	11.89	+5.88	15.40	16.26	+1.49

expected values for actual evapotranspiration. In 1960, heavy summer precipitation was recorded from May through September inclusive. During the same months in 1963, an acute precipitation deficiency existed. In 1967, April, June and September months were dry.

For Sion data from 1960-1969, Turc underestimated AE by 5.88 inches. Thornthwaite likewise underestimated AE by 1.51 inches from the expected value. Further, Turc showed a maximum unreliability in 1969 when the formula underestimated AE by 12.64 inches from the expected value. July, August and September of this year received heavy precipitation of 14.58 inches out of a total of 24.80 inches for the whole year. The year 1964 also showed underestimate of AE by 8.92 inches. It is worthy of note that the summer precipitation alone amounted to about 91 per cent of the total annual precipitation.

The mean monthly temperature for the above mentioned years did not show much variability. Therefore, it can cautiously be pointed out that the Turc method fails to give reliable AE estimates under highly variable precipitation conditions and especially when the variability of precipitation during the summer months is quite large.

CHAPTER IV

WATER BALANCE CHARACTERISTICS OF THE STURGEON WATERSHED

Since the early forties there has been an increasing interest among research workers concerned with water problems to define quantitatively the climatic water balance between precipitation and evapotranspiration. Thornthwaite (1944) realized that one could not determine whether a climate was arid or moist from the distribution in time and space of precipitation alone. He developed a climatic water balance (1948) utilizing a bookkeeping system in which climatic moisture increments or losses on either daily or monthly bases were compared with the climatic moisture needs for the same period. Efforts since then by numerous research workers all over the world have been useful in establishing the validity and limitations of this technique. Their work has been referred to elsewhere in the thesis and need not be repeated here.

The water balance method is an investigation of the quantities of water moving through the hydrologic cycle, or the continuity of flow of water. The water balance method, pursued in this research, may be expressed as

$$\text{Ppt.} = (PE - D) + S \mp Sc$$

Where Ppt. = Precipitation

PE = Potential evapotranspiration

D = Deficit

S = Surplus

Sc. = Storage change

If the amount of precipitation is greater than potential evapo-

transpiration, and if the soil is at field capacity, a water surplus will occur. If on the other hand, precipitation is less than potential evapotranspiration, moisture supply will be limited and a deficit will occur. Storage change is simply an expression of the difference in moisture carryovers from one year to the next because of different quantities of soil moisture utilization in each year. It may also be an expression of variation in snow pack moisture carried over from one year to another.

Ackerman (1958, p. ii) summarized the water balance concept as follows:

> "The water balance of a given land area, land region or surface water body of the earth most simply stated is an input-output calculation of moisture receipts, retention, and loss (expenditure, disappearance), over a given period of time".

Annual climatic water balance equations for six stations are given in Table 19.

Water deficit patterns:

Moisture deficit averaged over a period of 10 years (1960-1969) varied from 3 inches to 7 inches, deficits increasing in an easterly direction (Figure 12). Moisture deficit may be defined as the amount by which PE is not met either by precipitation or the stored soil moisture. Thus, water deficiency and droughts occur whenever the soil moisture is depleted to zero in the Thornthwaite 1948 procedures.

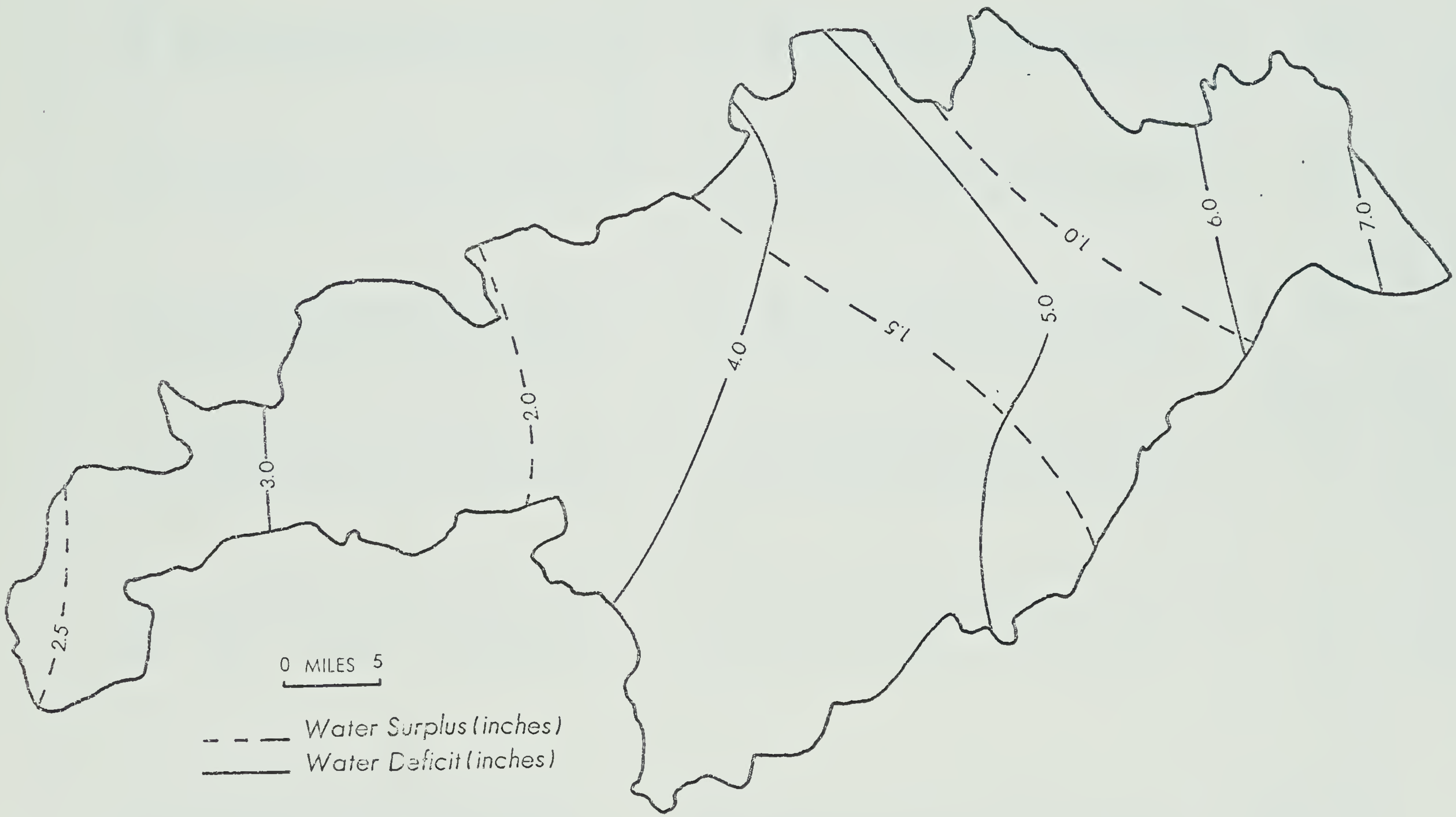
TABLE 18 - WATER DEFICIT PATTERNS FOR THE SELECTED STATIONS (4 IN. SOIL MOISTURE STORAGE)

Station	Maximum (inches)	Year	Minimum (inches)	Year(s)	Average (1960-1969) (inches)
Fort Saskatchewan	13.72	1963	0.39	1960	7.18
Edmonton Namao A	8.17	1967	1.69	1960	5.66
Sion	10.43	1967	0	1964	3.57
Peavine	11.65	1967	0	1962,1964	2.78
Edson	6.52	1967	0	1962,1964, 1965,1966, 1968,1969.	1.46
Moon Lake	6.67	1967	0	1962,1964, 1965.	2.54

The maximum water deficit value was obtained for Fort Saskatchewan. Edson showed a maximum water deficit of 6.52 inches. Decrease of moisture deficit in a westerly direction is indicated by the analysis of the data presented in Table 18. Further, large variation in the water deficit from one year to another and from station to station is also revealed by the above data.

Figure 13 indicates the monthly march of water balance patterns for the selected stations. Water deficiency generally develops during the month of June and persists until the end of October. Generally under wet summer conditions, duration of water deficiency may be shortened by heavy summer precipitation (Fort Saskatchewan, 1960) period. Also distribution of precipitation to counterbalance water demands during the summer months may lead to no deficit (Edson, 1965; Moon Lake, 1964; Peavine, 1964). In general, the largest water deficit occurs in the months of July and August.

FIGURE 12



MEAN ANNUAL WATER DEFICIT AND WATER SURPLUS PATTERNS FOR 4 INCH MOISTURE HOLDING CAPACITY

TABLE 19 - CLIMATIC WATER BALANCE (1960-1969)
AT 4 INCH MOISTURE HOLDING CAPACITY OF SOIL

Year	Ppt.	(PE - Deficit) (inches)	+ Surplus	± Storage Change
Edmonton Namao A				
1960	19.26	(21.22 - 1.69)	+ 0.73	- 1.00
1961	17.62	(21.69 - 5.23)	+ 0.96	+ 0.20
1962	16.84	(21.48 - 6.61)	+ 3.81	- 1.21
1963	11.45	(21.38 - 10.06)	+ 0.51	- 0.38
1964	16.80	(21.65 - 6.56)	+ 0	+ 1.71
1965	21.06	(20.64 - 3.84)	+ 5.49	- 1.23
1966	15.17	(19.58 - 4.56)	+ 0.50	- 0.35
1967	14.01	(20.17 - 8.17)	+ 0.53	+ 1.48
1968	14.36	(19.90 - 5.14)	+ 0.44	- 0.84
1969	18.02	(20.82 - 4.79)	+ 0.12	+ 1.87
Average	16.46	(20.83 - 5.66)	+ 1.25	+ 0.03
Fort Saskatchewan				
1960	20.87	(20.53 - 0.39)	+ 0.23	+ 0.50
1961	16.69	(21.83 - 6.29)	+ 1.58	- 0.43
1962	17.43	(21.93 - 5.83)	+ 2.78	- 1.45
1963	8.23	(22.13 - 13.72)	+ 0	- 0.18
1964	15.98	(22.06 - 7.17)	+ 0	+ 1.09
1965	17.78	(20.98 - 4.57)	+ 1.89	- 0.52
1966	13.69	(20.96 - 7.06)	+ 0	- 0.21
1967	10.89	(21.67 - 11.86)	+ 0	+ 1.08
1968	12.05	(20.62 - 7.52)	+ 0.17	- 1.22
1969	14.92	(21.53 - 7.42)	+ 0	+ 0.81
Average	14.85	(21.42 - 7.18)	+ 0.66	- 0.05

Table 18...

Year	Ppt.	(PE - Deficit) (inches)	+ Surplus	± Storage Change
Sion				
1960	18.79	(19.44 - 1.12)	+ 1.43	- 0.96
1961	17.16	(20.24 - 4.60)	+ 1.33	+ 0.19
1962	19.81	(18.87 - 1.32)	+ 3.45	- 1.19
1963	13.40	(20.97 - 9.07)	+ 1.78	- 0.28
1964	21.82	(20.08 - 0)	+ 0	+ 1.74
1965	17.55	(19.82 - 2.75)	+ 0.58	- 0.10
1966	16.21	(19.09 - 3.72)	+ 1.17	- 0.33
1967	10.96	(20.17 - 10.43)	+ 1.26	- 0.04
1968	16.76	(18.42 - 2.22)	+ 0	+ 0.56
1969	24.80	(19.66 - 0.47)	+ 3.44	+ 2.17
Average	17.73	(19.68 - 3.57)	+ 1.44	+ 0.18
Peavine				
1960	19.38	(20.49 - 1.54)	+ 0	+ 0.43
1961	21.06	(19.96 - 2.52)	+ 1.91	+ 1.71
1962	24.18	(20.44 - 0)	+ 4.75	- 1.01
1963	17.64	(21.51 - 6.42)	+ 3.55	- 1.00
1964	24.41	(20.48 - 0)	+ 1.33	+ 2.60
1965	21.63	(19.82 - 2.53)	+ 5.79	- 1.45
1966	18.81	(18.77 - 2.38)	+ 2.84	- 0.42
1967	10.76	(19.76 - 11.52)	+ 2.08	+ 0.44
1968	19.15	(18.42 - 0.05)	+ 0	+ 0.78
1969	21.70	(19.84 - 0.81)	+ 1.76	+ 0.91
Average	19.87	(19.95 - 2.78)	+ 2.40	+ 0.30

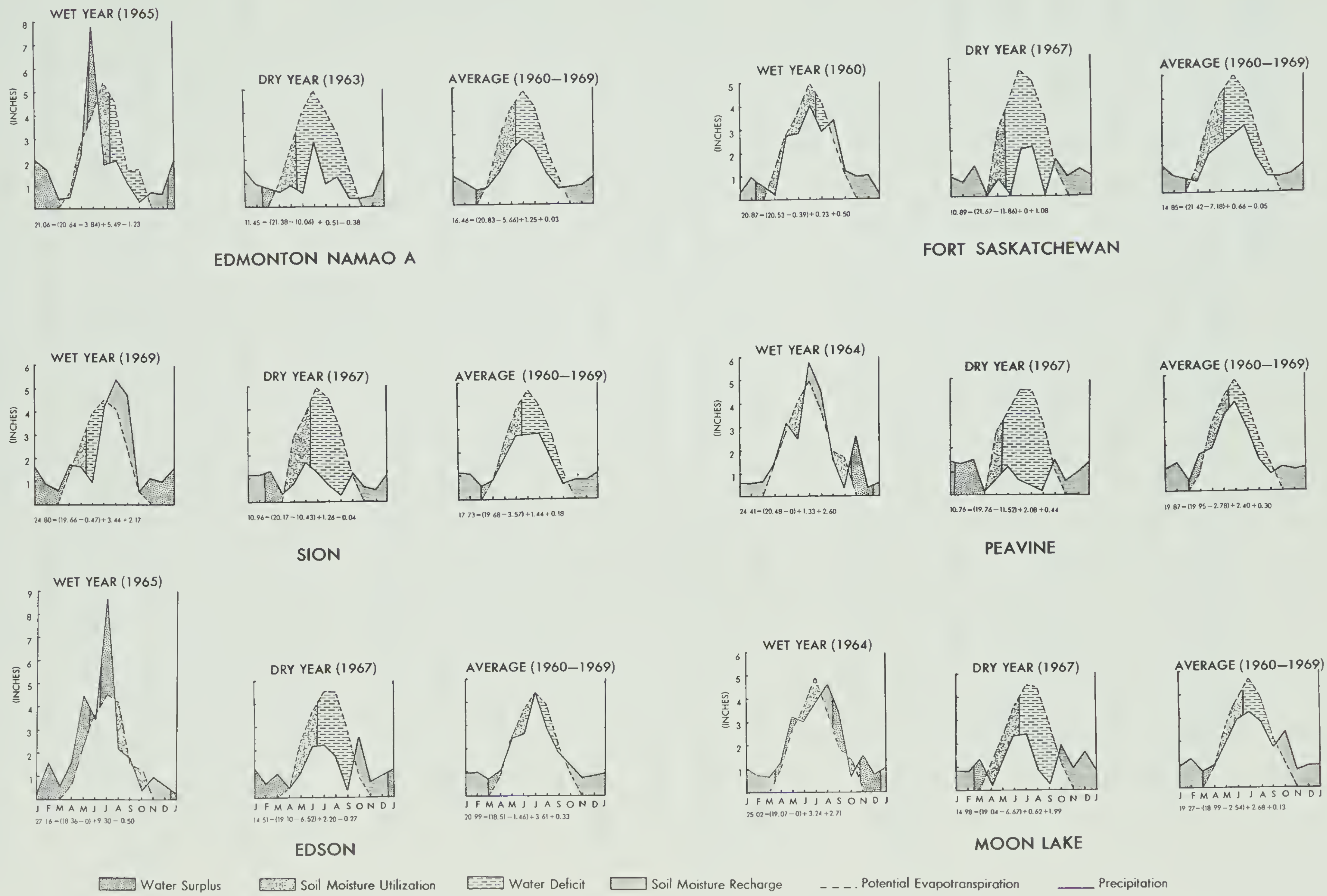
Table 18...

Year	Ppt.	(PE - Deficit) (inches)	+ Surplus	± Storage Change
Edson				
1960	19.25	(19.31 - 0.91)	+ 0	+ 0.85
1961	22.49	(19.43 - 1.84)	+ 2.96	+ 1.94
1962	24.09	(18.62 - 0)	+ 5.61	- 0.14
1963	17.45	(19.97 - 5.33)	+ 5.63	- 2.82
1964	24.31	(17.61 - 0)	+ 3.74	+ 2.96
1965	27.16	(18.36 - 0)	+ 9.30	- 0.50
1966	23.06	(16.89 - 0)	+ 5.44	+ 0.73
1967	14.51	(19.10 - 6.52)	+ 2.20	- 0.27
1968	17.48	(17.68 - 0)	+ 0.96	- 1.16
1969	20.09	(18.15 - 0)	+ 0.23	+ 1.71
Average	20.99	(18.51 - 1.46)	+ 3.61	+ 0.33
Moon Lake				
1960	18.71	(19.44 - 0.89)	+ 0.40	- 0.24
1961	18.64	(19.87 - 5.27)	+ 1.33	+ 2.71
1962	20.95	(18.62 - 0)	+ 3.85	- 1.52
1963	18.13	(20.04 - 5.39)	+ 4.67	- 1.19
1964	25.02	(19.07 - 0)	+ 3.24	+ 2.71
1965	24.02	(18.12 - 0)	+ 6.50	- 0.60
1966	18.26	(17.18 - 0.95)	+ 3.88	- 1.95
1967	14.98	(19.04 - 6.67)	+ 0.62	+ 1.99
1968	15.00	(18.58 - 3.61)	+ 2.31	- 2.28
1969	18.99	(19.94 - 2.59)	+ 0	+ 1.64
Average	19.27	(18.99 - 2.54)	+ 2.68	+ 0.13

FIGURE 13

COMPARISON OF CLIMATIC WATER BALANCE

(FOR 4 INCH MOISTURE HOLDING CAPACITY)



Water surplus patterns:

A comparison of the monthly record of PE and precipitation provides information on the changing patterns of moisture surplus shown in Figure 13. Average annual water surplus patterns for a period of 10 years are shown in Figure 12. Water surplus varied from 1.0 to 2.5 inches in a westerly direction. This trend is logically quite opposite to the one noted for the water deficit patterns (also on Figure 12). The trend lines have not been adjusted to topographic or land and water contrasts existing within the drainage basin.

On an average water surplus generally accumulates after the middle of March and continues well into April. The precipitation accumulation during the winter months is sufficient to recharge the soil moisture to its field capacity. As noted earlier, the mean monthly temperature for March is well below freezing during which PE theoretically is zero. An increase of temperature above 32°F would mean an increase in potential evapotranspiration or the climatic need at these stations. This increase in temperature would also cause surpluses to discharge earlier as snowmelt stream flow.

Wet years show surplus even in summer months and with abnormally high precipitation water surplus may result in any month of the year. This condition is well portrayed in Figure 13. The time of computed runoff and actual runoff, however, do not coincide. This is largely due to the effect of lakes, sloughs and topographic depressions and the non-contributing areas within the watershed (Figure 2). The later aspect of the ground water movement depends on the type of soil through which water must move.

The percentage of surplus water heldover each month and added to the surpluses of following months, as in Thornthwaite 1955-1957 procedures, has not been estimated at this level of investigation.

The mean annual computed water surplus for the study area at 4 inch soil moisture holding capacity is about 1.8 inches (Figure 12) as against the observed mean annual water surplus of 0.859 inch (Table 10) for the same period. The difference in observed and computed water surplus values may be explained by considering different moisture storages of soils of the study area. It has been noted in Figure 7 and Tables 4 and 5 that the soils of the Sturgeon watershed exhibit different moisture holding capacities. This variation within the same soil type may be significant. For example, loamy soils (Table 5) have at least three field capacity values. Considering the latitude of variation in these values it is not possible to determine the average moisture holding capacity of the soils within the watershed. An assumption that the average soil moisture storage is more than 4 inches would result in higher AE, lower deficit and lower surplus potential. Conversely, if this assumed limit is less than four inches then lower AE and higher deficit and surplus potentials will result.

Depth of rooting in different soils may also explain the above differences in observed and computed values. Further, forest cover might well imply an average of 6 inches of soil moisture storage. The use of this value, especially in the western sections of the drainage basin, would eliminate most of the difference between computed and measured stream flow.

Free-water evaporation is larger than the evaporation from land surfaces. As noted earlier, sloughs, swamps and lakes of varying depth and area occupy a considerable proportion of the drainage basin. Water surplus and water deficit values, however, have been computed for the land surfaces only. The difference in evaporation from land surfaces and water bodies could alone account for a large difference in observed and computed surpluses.

The problem of comparing estimated and observed water surpluses is further complicated by the presence of lakes in the study region. The extent to which water supply through the river channel is regulated by the lakes is exemplified by changes in observed lake level. The lake level observations at Lac Ste. Anne (Water Resources Division, 1969b) since 1933 show that the range of fluctuation has been from a low of 69.7 feet in 1939 to a high of 75.0 feet in 1944 and 1969. Lake levels in August and September of 1968 were approximately 71.0 feet. All elevations given above may be converted to G.S.C. datum by adding 2300 feet.

Fluctuation of water level at Isle Lake (Paul Sindhu, Personal communication, December 1970) given below also suggest that the major water bodies within the study region are a most important factor in water balance studies.

TABLE 20 - ISLE LAKE LEVELS FROM THE GIVEN G.S.C. DATUM OF 2378.95 FEET

Year	Elevation (Ft.)
1961	-0.96
1962	+1.12

Table 20...

Year	Elevation
1963	+0.02
1964	-0.88
1965	+0.86
1966	-1.66
1967	-0.81
1968	-0.81

Estimates by the Alberta Department of Agriculture (1969) suggest that about 8 per cent of the average annual precipitation enters the groundwater reservoir as natural recharge. This value, however, does not account for the role of evaporation from the water bodies and fluctuation of water level in the lakes. Analysis of the hydrograph (Fig. 10) does not support such an assumption.

Sturgeon watershed

Stream discharge data (1969) for the Sturgeon River near Villeneuve (Station 5EA-5, Figure 2) were kindly provided by Carl Primus. The computed water surplus at this station for 1969 and the total period discharge (Table 10) for the station showed values of 0.9 inch and 0.64 inch respectively. The latter computed value correlates better with actual stream flow than do the data previously presented for the Sturgeon basin as a whole.

CHAPTER V

SUMMARY AND CONCLUSIONS

Three empirical methods of estimating evapotranspiration were applied to the Sturgeon watershed in order to collect and collate information on spatial variability of potential evapotranspiration, actual evapotranspiration and the water balance patterns in the study area.

Six meteorological stations which reported at least ten years of temperature and precipitation data were selected close to the watershed boundary. A period from 1960 to 1969 only was considered since not all the stations were in operation prior to 1960. Data for the missing periods were computed by the method of interpolation.

The Sturgeon watershed is being intensively studied by engineers and agriculturists interested in 'climatic input-output' relationships from different viewpoints. The meagre experimental data on the consumptive use of water in the study area were tested against the computed values of evapotranspiration obtained by the application of Thornthwaite, Holdridge and Turc methods. Other pertinent data on evapotranspiration applicable to the study area were also applied to the observed and computed values.

Thornthwaite's method of estimating PE yielded better results as compared to the Holdridge technique. This comparison is possible only on an annual basis. However, when compared to measured values of PE for Fort Saskatchewan, Thornthwaite on an average gave lower estimates of PE by 7 to 12 per cent for June and July of 1967-1969. Data on potential evapotranspiration computed by the Penman technique

were available for Sion. For the months of May and June, Thornthwaite gave lower estimates of PE when compared to Penman. However, from July through August, Thornthwaite yielded higher estimates of potential evapotranspiration for the period between 1960 and 1969. On an annual basis these differences tend to disappear or reach a minimum stage. As a general note it may be stated here that PE in winter months, according to Thornthwaite, is zero which contributes to slightly lower estimates of potential evapotranspiration by this method.

Holdridge, when compared to Thornthwaite, yielded lower estimates of potential evapotranspiration for the study area. Unfortunately field data on annual PE are not yet available for the Sturgeon watershed and hence spatial patterns of potential evapotranspiration obtained by the application of the Holdridge technique cannot be tested against the field data.

Using a simple water balance technique, annual actual evapotranspiration computed by Thornthwaite's method at 4 inch soil moisture and Turc were compared. Thornthwaite's method yielded results very close to expected values (measured runoff). Turc, on the other hand, constantly gave lower estimates of AE for Fort Saskatchewan and Sion. The departure of computed AE was at its maximum for the dry years. Similarly, relatively wet years showed a large deviation from the expected AE. Such discrepancies make Turc unsuitable for the estimation of actual evapotranspiration in the study area.

The evapotranspiration values for the Sturgeon watershed suggested

in this research refer to minimum evapotranspiration occurring under average climatic conditions for the period studied. The presence of a large number of free-water evaporation surfaces tend to elevate evapotranspiration occurring under natural conditions. The patterns of evapotranspiration distribution shown likewise have not been adjusted to the prevailing geomorphic, biotic or hydrographic conditions.

The research has shown that the Thornthwaite technique holds better promise for estimating evapotranspiration in the study area than do the Holdridge or Turc methods. The dominant problem, however, is strongly attached to the understanding of average soil moisture holding capacity of the soils of the Sturgeon basin and the soil moisture - vegetation - evapotranspiration interrelationships. The Thornthwaite method of estimating water balance suggests that on an average the study area experiences a deficit of about 3.0 to 7.0 inches increasing in an easterly direction. The water surplus, on the other hand, increases in the opposite direction varying from about 1.0 to 2.5 inches. The moisture deficit generally develops in the months of July and August. A maximum water deficit of 13.72 inches was obtained for Fort Saskatchewan in 1963. The water surplus generally accumulates after the middle of March and continues well into April. During years of above average precipitation, and especially when the summer precipitation is heavy, water surpluses may also occur in the summer season.

Over 50 per cent difference between observed discharge and computed surplus cannot alone be accounted by a suggested loss of about 8 per cent of total precipitation to the groundwater recharge. Lake level

variations and increased evapotranspiration from lake surfaces are most probably important sources of such a discrepancy. The above investigation thus points out that the surplus patterns obtained for the study area are too high and if Thornthwaite has to serve a useful purpose some allowance would have to be made for variation in soil moisture storage in regions of mixed land use and soil type. Further, free-water surface evaporation should be calculated and incorporated for sub-basins where this seems an important item. Some knowledge of basin lag time is helpful even if this has to be extrapolated from elsewhere.

With these points in mind the Thornthwaite procedure may provide useful guidelines for estimating surpluses in regions of Prairie Provinces where discharge measurements are not available.

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APPENDIX I

POTENTIAL EVAPOTRANSPIRATION FOR SELECTED STATIONS

(INCHES)

Edmonton Namao A.

Year	Mar	Apr	May	June	July	Aug	Sept	Oct	Year
1960		1.38	2.79	3.67	5.34	4.12	2.54	1.38	20.82
1961		.69	3.59	4.89	4.93	4.87	1.90	.82	21.22
1962		1.38	2.79	4.48	4.52	4.12	2.54	1.65	21.69
1963		1.03	2.39	4.08	4.93	4.12	3.18	1.65	21.48
1964		1.38	3.19	4.48	4.93	4.12	1.90	1.65	21.38
1965		.69	2.79	4.08	5.34	4.50	1.59	1.65	21.65
1966		----	3.59	3.67	4.52	4.12	2.86	.82	20.64
1967		----	2.79	3.67	4.93	4.50	3.18	1.10	19.58
1968		1.03	2.79	4.08	4.93	3.75	2.22	1.10	20.17
1969		1.72	3.19	4.48	4.52	4.12	2.22	.55	19.90
Aver.		.93	2.99	4.16	4.89	4.23	2.41	1.24	20.83

Fort Saskatchewan

Year	Mar	Apr	May	June	July	Aug	Sept	Oct	Year
1960		1.38	2.79	3.67	4.93	4.12	2.54	1.10	20.53
1961		.69	3.59	5.30	4.93	4.87	1.90	.55	21.83
1962		1.38	3.19	4.48	4.52	4.12	2.86	1.38	21.93
1963		1.38	2.79	4.08	4.93	4.12	3.18	1.65	22.13
1964		1.38	3.19	4.48	5.34	4.12	1.90	1.65	22.06
1965		1.03	2.79	4.08	5.34	4.50	1.59	1.65	20.98
1966		.69	3.59	3.67	4.93	4.12	2.86	1.10	20.96
1967		----	2.79	4.08	5.34	4.87	3.49	1.10	21.67
1968	.30	1.03	3.19	4.08	4.93	3.75	2.54	1.10	20.62
1969		2.07	3.19	4.48	4.52	4.50	2.22	.55	21.53
Aver.	0.03	1.13	3.11	4.24	4.97	4.31	2.51	1.18	21.42

Appendix I...

Year	Mar	Apr	May	June	July	Aug	Sept	Oct	Year
Sion									
1960		1.38	2.39	3.67	4.93	3.75	2.22	1.10	19.44
1961		.69	3.19	4.89	4.52	4.50	1.90	.55	20.24
1962		1.03	2.39	3.67	4.11	3.75	2.54	1.38	18.87
1963		1.03	2.39	3.67	4.93	4.12	3.18	1.65	20.97
1964		1.03	2.79	4.08	4.52	3.75	1.90	1.65	20.08
1965		.69	2.79	3.67	4.93	4.50	1.59	1.65	19.82
1966		----	3.19	3.67	4.52	3.75	2.86	1.10	19.09
1967		----	2.79	3.67	4.93	4.50	3.18	1.10	20.17
1968		1.03	2.79	3.67	4.52	3.37	2.22	.82	18.42
1969		1.38	2.79	4.08	4.52	4.12	2.22	.55	19.66
Aver.		0.83	2.43	3.87	4.64	4.01	2.38	1.15	19.68
Peavine									
1960		1.38	2.79	3.67	4.93	4.12	2.22	1.38	20.49
1961		----	3.19	4.89	4.93	4.50	1.90	.55	19.96
1962		1.38	2.79	4.08	4.52	3.75	2.54	1.38	20.44
1963		1.03	2.79	4.08	4.93	4.12	3.18	1.38	21.51
1964		1.38	2.79	4.08	4.93	3.75	1.90	1.65	20.48
1965		.69	2.79	3.67	4.93	4.50	1.59	1.65	19.82
1966		0	3.19	3.67	4.52	3.75	2.54	1.10	18.77
1967		0	2.79	3.67	4.52	4.50	3.18	1.10	19.76
1968		1.03	2.79	3.67	4.52	3.37	2.22	.82	18.42
1969		1.38	2.79	4.08	4.52	3.75	2.22	1.10	19.84
Aver.		.83	2.87	3.96	4.72	4.01	2.35	1.21	19.95

Appendix I...

Year	Mar	Apr	May	June	July	Aug	Sept	Oct	Year
Edson									
1960		1.38	2.39	3.26	4.93	3.75	2.22	1.38	19.31
1961		.69	2.79	4.48	4.52	4.50	1.90	.55	19.43
1962		1.38	2.39	3.67	4.11	3.75	2.22	1.10	18.62
1963		1.03	2.39	3.67	4.52	4.12	2.86	1.38	19.97
1964		.69	2.39	3.67	4.52	3.37	1.59	1.38	17.61
1965		.69	2.39	3.67	4.52	4.12	1.59	1.38	18.36
1966		----	2.79	3.26	4.11	3.37	2.54	.82	16.89
1967		.34	2.39	3.67	4.52	4.50	2.86	.82	19.10
1968		.69	2.39	3.67	4.52	3.37	2.22	.82	17.68
1969		1.38	2.79	3.67	4.11	3.75	1.90	.55	18.15
Aver.		0.83	2.51	3.67	4.44	3.86	2.19	1.02	18.51
Moon Lake									
1960		1.38	2.39	3.67	4.93	3.75	2.22	1.10	19.44
1961		.69	2.79	4.89	4.93	4.12	1.90	.55	19.87
1962		1.38	2.39	3.67	4.11	3.75	2.22	1.10	18.62
1963		.69	2.39	3.67	4.93	4.12	2.86	1.38	20.04
1964		1.03	2.79	3.67	4.93	3.37	1.90	1.38	19.07
1965		.69	2.79	3.67	4.52	4.12	.95	1.38	18.12
1966		----	2.79	3.26	4.52	3.75	2.86	----	17.18
1967		----	2.39	3.67	4.52	4.50	2.86	1.10	19.04
1968		1.03	2.39	3.67	4.52	3.37	2.22	1.38	18.58
1969		1.38	2.79	4.08	4.11	3.75	1.90	1.93	19.94
Aver.		0.83	2.59	3.79	4.60	3.82	2.19	1.13	18.99

APPENDIX 2

MEAN MONTHLY TEMPERATURE (°F) FOR SELECTED STATIONS

Edmonton Namao A.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1960	8.2	12.6	19.4	41.9	49.1	55.4	66.4	59.8	52.4	43.2	23.4	19.7	38.2
1961	16.8	16.4	26.6	37.2	53.3	62.5	63.8	65.9	46.9	39.0	22.1	1.0	37.6
1962	12.4	4.3	16.4	40.7	50.8	59.4	59.9	59.7	52.4	44.5	30.4	18.0	32.4
1963	3.7	17.1	26.3	39.5	48.4	59.0	64.6	62.7	58.0	46.2	19.8	7.8	37.0
1964	12.5	26.0	14.3	39.9	51.4	59.1	64.2	58.7	46.3	44.7	20.0	-4.5	36.0
1965	2.3	7.8	14.6	36.5	49.1	56.7	64.0	63.2	42.3	45.8	17.6	12.0	34.3
1966	-10.2	11.5	22.0	32.6	52.9	55.3	61.2	58.3	54.8	39.2	13.8	12.4	33.6
1967	3.2	13.4	12.5	30.4	49.7	56.3	62.5	64.7	58.9	41.1	26.5	12.7	35.9
1968	2.6	18.0	32.9	38.6	50.3	56.8	61.9	56.6	50.2	39.7	22.8	1.2	35.9
1969	-17.4	7.5	19.8	43.4	51.1	58.9	60.5	60.3	49.2	35.1	28.5	22.0	36.0

Fort Saskatchewan

1960	4.4	10.1	16.8	42.0	49.4	56.0	63.4	60.5	52.7	42.1	21.8	17.3	36.6
1961	13.4	16.3	25.8	37.2	54.0	65.5	63.3	65.3	47.0	36.6	18.7	-2.9	36.7
1962	12.3	4.4	13.0	40.8	51.2	59.6	59.7	59.6	52.8	44.1	30.1	18.1	37.1
1963	4.6	16.7	27.2	40.6	49.8	59.3	65.1	62.9	58.1	45.8	19.9	12.7	38.5
1964	12.5	25.7	14.6	40.2	51.8	59.5	64.2	59.4	47.1	44.5	20.6	-4.8	36.2
1965	1.5	7.7	13.7	37.7	50.4	57.6	64.6	63.2	42.5	45.7	17.5	10.3	34.3
1966	-11.4	10.4	21.6	34.8	58.3	56.1	61.8	58.7	55.1	40.0	15.6	11.0	33.9
1967	2.1	13.3	12.6	30.2	50.0	56.7	64.1	65.6	59.1	40.4	26.2	12.8	36.0
1968	3.2	18.0	33.4	38.8	50.7	56.8	61.5	57.0	50.8	39.6	28.7	0.8	36.6
1969	-18.7	6.5	19.9	44.3	51.9	59.7	61.1	61.4	50.5	35.7	28.8	20.0	36.4

Appendix 2...

Sion

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1960	8.0	12.9	19.2	40.7	47.5	53.1	63.1	57.8	50.5	42.0	22.7	19.7	36.4
1961	17.1	16.7	26.3	36.0	51.3	61.9	60.8	62.3	45.0	37.0	20.1	-2.1	36.0
1962	10.8	2.4	16.4	38.3	47.6	55.7	56.4	56.6	52.0	44.0	29.6	17.3	35.5
1963	4.5	17.5	26.6	38.8	47.2	56.5	62.7	60.6	58.3	45.5	19.3	14.1	37.6
1964	14.6	28.6	14.1	38.5	49.1	56.5	60.8	57.5	46.1	45.7	20.4	3.0	38.1
1965	7.9	8.5	17.9	36.8	49.2	55.8	62.9	61.7	42.6	46.4	17.6	13.3	34.8
1966	-9.6	14.2	24.2	32.6	52.3	54.3	59.8	57.5	53.6	40.1	14.6	13.8	33.9
1967	3.7	15.1	12.9	31.6	50.2	55.8	62.4	64.3	58.7	41.3	27.0	12.2	36.2
1968	1.6	16.7	31.0	38.3	49.4	55.0	59.4	54.3	48.8	38.2	26.9	-1.8	34.8
1969	-19.5	7.1	19.8	42.2	50.2	57.2	58.8	58.6	48.6	35.0	28.0	23.1	32.1

Peavine

1960	7.6	13.6	20.4	41.6	48.4	54.9	63.5	58.4	50.7	42.6	21.9	19.3	36.8
1961	17.4	16.2	27.1	37.2	52.1	62.7	61.7	62.4	45.8	37.7	20.4	-2.2	36.5
1962	10.5	2.7	17.1	39.6	48.6	57.0	58.6	58.0	51.6	43.6	27.5	16.6	35.9
1963	5.5	16.3	28.1	38.5	48.1	56.7	62.8	60.2	56.4	44.1	17.6	14.0	37.3
1964	13.3	29.8	15.0	39.7	50.4	57.1	61.7	56.4	45.9	45.1	21.2	-4.6	35.9
1965	2.0	7.8	17.2	36.2	48.7	55.6	62.6	62.0	43.2	45.4	16.4	10.1	33.0
1966	-12.0	12.6	23.4	33.0	52.1	53.4	59.7	57.5	52.6	40.5	16.4	12.8	33.5
1967	2.8	14.5	14.2	32.4	49.4	55.8	61.8	63.6	57.5	40.9	26.3	13.1	36.0
1968	3.2	17.2	31.9	38.4	50.5	55.9	60.4	55.0	49.2	38.0	25.6	0.0	35.4
1969	-15.1	5.9	19.4	41.4	50.5	57.0	58.3	57.7	47.8	36.9	28.5	22.8	34.2

Appendix 2...

Edson

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1960	11.2	17.0	21.5	40.1	45.8	52.2	63.2	57.1	49.9	42.7	25.2	21.8	33.7
1961	19.9	19.2	29.4	37.1	49.9	60.6	61.1	61.4	45.4	36.9	31.9	4.9	38.1
1962	13.4	9.2	20.2	40.4	46.0	55.1	57.5	56.7	49.5	41.9	27.3	18.4	36.2
1963	7.7	22.2	28.3	38.3	46.0	55.1	60.4	58.8	54.9	42.7	19.1	14.8	37.3
1964	14.1	30.0	17.6	36.8	46.9	55.6	59.2	54.8	44.2	43.0	20.5	-4.2	34.8
1965	2.7	13.8	18.5	36.4	46.4	53.7	60.2	60.4	42.3	43.0	17.8	9.6	36.4
1966	-6.6	17.7	25.4	31.9	49.8	52.3	57.7	56.2	52.5	37.8	15.1	13.8	40.9
1967	6.3	20.9	16.4	33.7	46.3	54.7	59.0	61.3	55.1	38.0	27.3	14.8	36.1
1968	5.4	18.9	31.8	36.5	47.0	52.8	58.5	53.9	48.8	37.9	25.4	0.2	34.7
1969	-16.8	11.8	25.6	42.2	49.1	55.9	57.3	56.7	47.3	36.4	28.5	22.0	35.1

Moon Lake

1960	6.3	12.5	21.1	39.9	47.4	53.0	62.7	57.7	49.4	42.1	23.4	19.0	36.2
1961	17.0	16.3	27.5	36.5	50.3	61.6	61.6	61.2	45.3	36.1	19.5	-0.3	36.0
1962	10.9	4.1	17.4	40.0	47.3	55.6	57.2	56.8	50.6	42.0	28.9	17.8	35.7
1963	7.1	19.9	27.8	37.5	47.0	55.9	61.8	59.7	55.7	43.1	18.3	12.8	37.2
1964	11.0	27.3	14.7	38.2	48.7	56.1	61.3	55.8	45.6	44.0	21.3	-5.4	34.8
1965	16.6	10.1	15.6	36.0	47.8	54.5	61.0	60.7	42.9	44.0	17.4	9.0	34.6
1966	-9.6	13.5	24.7	32.2	50.3	52.1	58.6	56.8	56.1	32.8	14.8	12.1	32.8
1967	2.7	16.2	13.7	32.8	46.9	55.2	59.9	61.9	55.4	39.5	25.7	10.6	35.0
1968	4.0	18.1	32.0	37.9	47.6	53.3	59.1	53.8	50.1	43.7	27.0	0.5	35.6
1969	-17.0	9.1	22.7	42.2	49.8	56.5	57.4	56.6	47.1	48.3	28.6	23.0	35.3

APPENDIX 3

MEAN MONTHLY PRECIPITATION FOR SELECTED STATIONS (INCHES)

Edmonton Namao A.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1960	.60	.59	.38	.15	2.62	2.38	2.66	4.02	2.32	1.47	.94	1.13	18.02
1961	.33	1.52	.31	1.33	.70	4.89	4.01	.37	.98	1.14	1.02	1.02	19.26
1962	1.18	2.20	1.35	1.47	1.66	2.26	2.62	1.60	.96	.39	.33	.82	17.62
1963	1.58	.99	.79	.61	.89	.55	2.72	.94	1.26	.35	.35	.42	16.84
1964	1.50	.54	.56	.77	2.64	1.10	2.44	2.09	2.35	.33	1.65	.83	11.45
1965	2.05	1.64	.37	.42	2.34	7.75	1.87	2.08	1.03	.26	.66	.59	16.80
1966	1.56	.65	.16	.88	1.35	.78	2.80	5.55	.37	.17	.54	.36	21.06
1967	1.17	.68	1.26	.52	.94	1.48	2.49	1.92	.07	1.55	.75	1.18	15.17
1968	1.10	.38	.58	1.03	.26	2.07	2.74	2.85	1.31	.50	.08	1.46	14.01
1969	1.12	1.06	.40	.78	1.00	.31	3.81	3.34	3.23	.98	.97	1.00	14.36
Aver	1.22	1.02	0.62	.80	1.44	2.36	2.82	2.48	1.39	0.71	0.73	0.88	16.46

Fort Saskatchewan

1960	.25	.94	.53	.20	2.70	2.80	4.00	2.90	3.40	1.20	1.00	1.05	20.87
1961	.38	1.70	.38	.80	.70	3.70	4.70	.20	1.00	1.60	0.73	.80	16.69
1962	1.71	1.67	.82	1.10	2.90	3.30	.30	2.80	1.00	.70	.40	.73	17.43
1963	1.80	.48	.50	.80	.90	----	.80	.60	1.00	.40	.35	.60	8.23
1964	1.28	.40	.21	.26	2.52	1.43	2.70	2.77	2.14	.32	1.54	.41	15.98
1965	2.00	.60	.37	.20	2.17	6.50	.91	2.05	1.32	.23	.78	.65	17.78
1966	1.70	.50	.15	----	----	.81	2.71	6.13	.32	.15	.67	.55	13.69
1967	.82	.60	1.27	----	.70	----	2.00	2.10	----	1.50	.80	1.10	10.89
1968	.92	.50	.45	.80	.20	1.20	2.70	2.40	1.50	.30	.05	1.03	12.05
1969	.79	.65	.63	.71	.79	.17	3.17	3.35	3.19	.47	.50	.50	14.92
Aver	1.16	0.71	0.53	0.49	1.61	1.99	2.40	2.82	1.49	0.69	0.68	0.74	14.85

Appendix 3...

Sion

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1960	1.31	1.12	.50	.21	2.25	3.60	1.68	3.89	2.28	.95	1.25	1.24	18.79
1961	.57	1.53	.28	1.10	.82	4.74	2.63	.70	1.51	1.57	.94	.77	17.16
1962	1.16	2.08	.43	1.47	3.00	3.07	3.35	1.64	1.23	.84	.46	1.08	19.81
1963	1.81	1.33	1.10	.91	1.40	.71	2.51	1.37	.90	.10	.59	.67	13.40
1964	.57	.67	.22	.83	4.07	2.42	3.61	3.71	2.37	.29	1.70	1.00	21.82
1965	.50	1.45	.22	.61	2.37	5.29	2.35	2.55	1.02	----	1.13	.51	17.55
1966	1.85	.56	.44	.68	1.54	1.42	3.23	4.43	.57	.18	.78	.53	16.21
1967	1.14	1.18	1.30	.33	.76	1.70	1.29	.61	.28	1.23	.64	.50	10.96
1968	.91	.53	.71	1.05	.29	3.07	2.45	3.81	1.30	.82	.07	1.76	16.76
1969	1.60	.90	.64	1.73	1.65	.96	4.31	5.42	4.85	.57	1.17	1.00	24.80
Aver	1.14	1.13	0.58	0.89	1.81	2.70	2.74	2.81	1.67	0.65	0.87	0.85	17.73

Peavine

1960	.41	1.10	.57	.55	1.46	4.96	3.39	3.24	1.67	.33	.75	.95	19.38
1961	.51	1.07	.43	1.44	1.12	5.75	4.85	.53	1.40	2.05	1.15	.76	21.06
1962	1.37	2.32	.56	2.47	2.63	3.75	4.52	2.68	1.02	.79	.87	1.20	24.18
1963	1.81	1.59	1.28	1.50	1.05	1.47	4.22	1.81	.99	.52	.86	.54	17.64
1964	.58	.53	.61	1.45	3.14	2.48	5.74	4.56	1.55	.32	2.57	.88	24.41
1965	.50	1.92	.13	.59	2.90	6.90	2.44	2.60	1.04	.06	1.22	.83	21.63
1966	1.92	.96	.43	1.48	1.85	1.80	5.15	3.21	.19	.19	1.25	.38	18.81
1967	1.48	1.34	1.51	.12	.66	1.22	.66	.41	.19	1.55	.62	1.00	10.76
1968	.50	.55	.66	.87	2.22	2.61	3.41	3.44	.72	1.01	1.00	1.66	19.15
1969	1.00	1.22	.69	1.16	1.57	1.23	4.00	4.67	4.32	.50	.46	.88	21.70
Aver	1.00	1.26	0.49	1.63	1.90	3.22	3.84	2.71	1.34	0.73	1.07	0.91	19.87

Appendix 3...

Edson

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1960	.62	.83	.23	.51	3.27	4.03	2.65	2.52	1.82	.71	.78	1.28	19.25
1961	.79	.67	.40	1.24	2.64	2.19	4.51	1.31	1.70	4.21	1.31	1.52	22.49
1962	1.27	2.03	1.12	.59	3.55	1.97	6.63	2.54	1.79	1.11	.39	1.10	24.09
1963	1.61	1.88	1.03	2.28	1.30	.80	2.19	2.52	1.69	1.11	.71	.33	17.45
1964	.74	.42	.79	1.63	2.74	3.54	5.14	2.83	4.40	.13	.92	1.03	24.31
1965	.28	1.55	.55	1.62	4.47	3.45	8.65	2.17	1.77	.35	.98	.60	27.16
1966	1.37	1.14	.95	0.94	2.52	1.31	4.92	7.04	.91	.72	.98	.26	23.06
1967	1.21	.51	.97	.33	1.04	2.14	2.27	1.72	.26	2.52	.64	.90	14.51
1968	.86	.37	.49	.53	1.42	4.12	4.26	2.20	1.46	.40	.31	1.06	17.48
1969	.91	.74	.50	1.23	1.83	2.83	2.98	3.54	3.00	1.18	.45	.70	20.09
Aver	0.96	1.01	0.70	1.09	2.48	2.64	4.42	2.84	1.88	1.24	0.75	0.88	20.99

Moon Lake

1960	.55	1.43	.81	.53	2.71	4.28	1.82	2.36	2.66	.27	.29	1.00	18.71
1961	.26	.72	.77	1.12	.85	2.91	3.98	.86	1.29	2.86	1.59	1.43	18.64
1962	.81	2.32	.72	.85	2.71	2.91	3.72	3.21	1.64	.80	.18	1.08	20.95
1963	2.59	1.76	.86	1.67	1.17	2.08	3.92	1.32	1.32	.15	.67	.62	18.13
1964	1.09	.77	.69	1.27	3.27	3.03	3.84	4.66	3.44	.62	1.59	.75	25.02
1965	.24	2.45	.36	1.26	3.81	6.67	3.08	3.33	1.25	.12	.89	.71	24.02
1966	1.83	.84	.27	1.53	1.30	2.71	3.61	3.80	.91	.38	.86	.22	18.26
1967	.85	.80	1.34	.17	1.38	2.33	2.44	.88	.24	1.95	.95	1.65	14.98
1968	.87	.40	.59	.84	1.12	2.06	2.80	3.00	1.17	.98	.17	1.00	15.00
1969	.74	.86	.58	.80	1.66	.65	3.31	4.70	3.19	1.13	.47	.90	18.99
Aver	0.98	1.23	0.70	1.00	2.00	2.96	3.25	2.81	1.71	2.41	0.77	0.94	19.27